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Book 9

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Book 9

Research + Computation Diarys

Continued from Book 8 on 6/27/66

Table

2

.04

		ε .01	εpeak = .02	εpeak at .2
		615.552		
615.551		VVF in ①	VF in ①	VS in ①
	peak T	.035	.060	.43
	foot to peak	.033	.057	.41
		.165 msec	.285 msec	2.05 msec
			50% down .205 50% up .022 .183	
	halfwidth	.12	.183	.913 (615.552)
		.60	.915 msec	4.56
	Vp/slope for τ=5 msec	.098 msec	~~.185~~ msec	1.3 msec

Table

615.554	peak V	$.596 \times 10^{-3}$	$.3905 \times 10^{-2}$
	peak T	.23	.68
	foot to peak	.19	.58
		.95 msec	2.9 msec
	Vp/slope for τ=5 msec	.56 msec	1.9 msec
615.554B	halfway down T=	.78	1.525
	halfway up	.095	.30 –
	halfwidth	.68	1.225+
	for τ = 5 msec	3.4 msec	6.13 msec

6/27/66

Going over computer output received 6/24 & 6/27

615.551 VF & VS trans. in cpt. ① of ten
VF means very fast E trans (λ=50.) – this was complete
VS " very slow " " (λ=5.) – did not get halfway down

∴ setup 615.552 to complete VS and get VVF with λ=100.

615.554 VF & VS in ④ of ten.
Need more time for both, put in for rerun.

665.101 two different EPSP in Branchlet; needed $\lambda_{18,3}$ card

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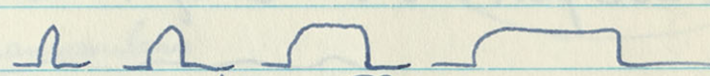
664.115 – 664.145 
in ① of ten and in ⑯ alone
Most of these need more time for ⑯
Also, depol in ⑯ was about 0.25,
which is really too much.
∴ put in rerun's with E cut to 1/3 & longer time in ⑯

Prepared chart for ① for time to peak, width at half ampl, etc.

These figures are needed for plots to be included in joint paper with Bob Burke, Phil Nelson, etc., which we discussed & examined preliminary plots on Friday (6/24/66).

For E transient $F(T) = kTe^{1-kT}$

peak at $kT_p = 1$ because then $F(T_p) = 1e^{1-1} = 1$

halfwayup at $kT_{hup} \simeq 0.232$ because

$$(0.23)(e^{.77}) = (.23)(2.16) = .497$$
$$(0.24)(e^{.76}) = (.24)(2.138) = .513$$

halfwaydown at $kT_{hd} \simeq 2.68$ because

$$(2.68)(e^{1.68}) = (2.68)(.18637)$$
$$= .499$$

$$\therefore \frac{\text{halfwidth}}{\text{time to peak}} = \frac{2.68 - .232}{1} \simeq 2.45$$

for all fast or slow E of this general form.

$$\frac{dF}{dT} = ke^{1-kT} + kT(-k)e^{1-kT}$$
$$= k(1-kT)e^{1-kT}$$

for $kT_{1/2\,up}$ get $\frac{dF}{dkT} = \frac{1-kT}{kT} \times \frac{1}{2}$

$$= \frac{.768}{.232}\left(\frac{1}{2}\right)$$

$$= 1.65_5$$

which is close to the 1.6 found for the EPSP

6/27/66 Did referee job for Windle this afternoon
Received Ditto copy of Molnar Thesis & letter from Cechner & Case
6/28/66 Continue going over output.

Need to finish Ve papers

615.501 VF trans in all cpts.

Rerun for longer time

peak T = .114
peak ampl = .048
missed halfway down
50% up, T = .030~~7~~
10% up, T = .010
foot = .005
foot to peak = 0.110
for τ = 5 msec, get 0.55 msec

6/30/66
.831
.031
halfwidth .800
for τ = 5 msec
get ~~40~~
4.0 msec

slope/v_p = 17.7 dimensionless
for τ = 5 msec = 3.54 msec^{-1}
v_p/slope = 0.28$_3$ msec

This fits pretty well on the common v_p/slope vs time to peak line

1→4 corresp to $\Delta Z = 3(.4) = 1.2$

615.042 ε in ④ with $Z_m = 4.0$, for trans. $\tau/25$
peak time is 0.58
50% at .26
10% at .135
foot at .10
from foot time to peak = ~~0.36~~ 0.48
for τ = 5 msec ≃ ~~1.8~~ msec
2.4 msec

which does agree approx with Table I between cpts. 6 & 8 i.e. cpt 7
$\Delta Z = 6 \times (.2) = 1.2$

6/28/66

666.004 Electric Coupling compare with p.188 book 8

Here, tried making Cpt.6 much smaller than before and compensatorilly increasing $R_{o,6}$, to see if V_K becomes more nearly proportional to V_A.

Got ~~time~~ factor trouble, because of larger τ

But first, compare what got here with 666.003

peak neg Q in 6 fell to about 1/3, but neg V_6 approx doubled.

V_8 is same as before , $V_{10} = V_K$ seems neg all the way.

$\therefore V_K = V_8 + V_6$ is ~~presumably reduced~~ goes neg.

$\therefore$ expect V_5 also reduced. peak $Q_5 = .052$ at .06 not diphasic

~~in 666.003 before T.C. peak $Q_5 = .0789$~~ is diphasic

Thus, this device of reducing coupling capacity did ~~reduce~~ eliminate the diphasic effect at (5), but it also had the unexpected effect of making V_K neg. Presumably this simply means that V_K is at different point along potential divider from V_5 to V_8, but maybe there is an error in the setup. This must be reexamined.

666.204

Here, avoided blow up of 202 & 203.

Also steady state now seems O.K. — input is to (5)

Q_6 is smaller than V_5
& Q_7 is pos.
Q_9 is zero
} seems reasonable now.

Q_1 peaks .00164 at T = .45

Q_5 .0562 .030

turns neg at T = .18

Q_6 is neg for all T, peaks at T = .04

Q_7 (axon) peaks at T = .03, peak V_7 = .82

$\mathcal{E}$ peaks at T = .02

Summer 13 corresp V_6 peaks at ~~zero time~~ between zero & T = 0.02 at .27

* But do not understand why Q_5 diphasic when (13) is not ? error in setup.

665.102

Sum
ε=1. in 3,4,5
ε=2. in 3

separate ε=1. in 2&3

(4)p

				too large	earlier than before
(1)	peak V = .0245 at T = ~~.50~~ .40			peak V = .02856 at T =	.25
(3)	.55	~~.0687~~	.10	.2736	.01
(4)	.61	~~.038~~	.14	.109	.22
(5)	.70	~~.043~~	.14	.084	.38

	at T = .35	T = .40	T = .45
3,4,5 alone gave	.01402	.01454	.01478
3 alone gave	.01576	.01552	.01505
	.02978	.03006	.02983
combined gave	.02422	.02~~4~~454	.02444
	81%+	82%	81%+

	at T = .~~45~~50	T = .55	.60
3,4,5	.01483	.01475	.01459
3	.01449	.01390	.01333
	.02932	.02865	.02792
combined	.02410	.02363	.02308
	82%	82%	82%

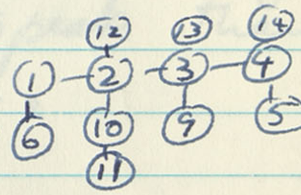
∴ 18% loss

6/28/66 fresh output

615.554 VF & VS E in (4) of ten, see pp 3 & 4.
for incorporation of results –

615.552 VVF + VS ~~E~~ in (1) see pp 3 & 4

665.101 Branchlet E, Two EPSP
refer back to p. 186 of book 8



St. St. input resistance
at (4) is 16× (.1338)
= 2.14
compare p. 184
book 8

	First EPSP ~~medium~~ fast E = 1 in 3,4,5		Second EPSP ~~medium~~ fast E = 2 in (3) alone	
(1)	peak V = .01483	at T = .50	.01576	at T = .35
(3)	.2986	.10	.40	.08
(4)	.5441	.12	.152	.20
(5)	.6722	.14	.115	.34

amplitudes not quite as large as wanted, which were .017 and .022 in (1)
peak times not quite as different as wanted .6 .2
But good enough to try for a summation & see what happens.
Also, after T.C., try E = 1 in 2 & 3 ~~for faster one~~ → to get earlier peak

664.115 B, 125 B, 135 B, 145 B reruns to analyse
↑ These results now entered in chart
with E reduced to 1/3
& more time

prepared 615.556 & .558 VVF & VF in (6) & (8)
put in late 6/28/66

6/29/66

prepared 615.999 fast trans, in which $\mathcal{E}$ in each compartment was set to that which alone would make EPSP peak = 0.01. This may give a larger halfwidth / time to peak than uniform in all compartments does.

Used $\lambda_{1,12} = \lambda_{15,1} = 0.26 \times Q_{14}$

2,12	15,2	0.41
3,12	15,3	0.61
4,12	15,4	0.89
5,12	15,5	1.3
6,12	15,6	1.7
7,12	15,7	2.15
8,12	15,8	2.6
9,12	15,9	2.8
10,12	15,10	3.1
0,12		$-15.82 \times Q_{14}$

6/30/66 found 615.999 had too many data points: fixed & resubmitted

615.501 VF in all cpts. — now complete p. 6

615.502 & setup VVF with $\lambda = 100$.

665.103 modify branchlet GE to provide for $\mathcal{E} = 0.7$ in 2 & 3 after T.C.

see p. 9 for 665.102

This plus $\mathcal{E} = 1.$ in 3, 4, 5 before T.C.

*The error was pinpointed by checking results for 5 cpt chains & verifying that these points fall on same curves, except for the incorrect (10) often point.

	VVF in (8)		VF in (8)	
peak amp.	$.1014 \times 10^{-3}$		$.2024 \times 10^{-3}$	maybe less .66
peak time	.65+, say .66		.70 −, say .68 −.66	
50%	.265		.288	
10%	.14		.155	
foot	.11		.124	
foot to peak	.54	.55	.576	.556 54
for τ=5	2.7	2.75	2.83	2.78
half down	1.67		1.705	
half up	.27		.288	
halfwidth	1.4		1.42	
for τ=5	7.0		7.1	

6/30/66 received lots of output, see previous page as well.
Also found error in slow trans (10) of (10) halfwidth
(see left *) ↖ hand interp error on 655.110, need to correct Table II

Now look at 615.556B & 558
VVF & VF

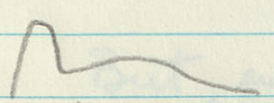
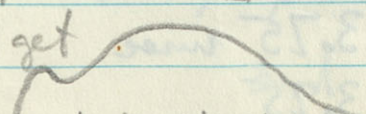
put in 5/10

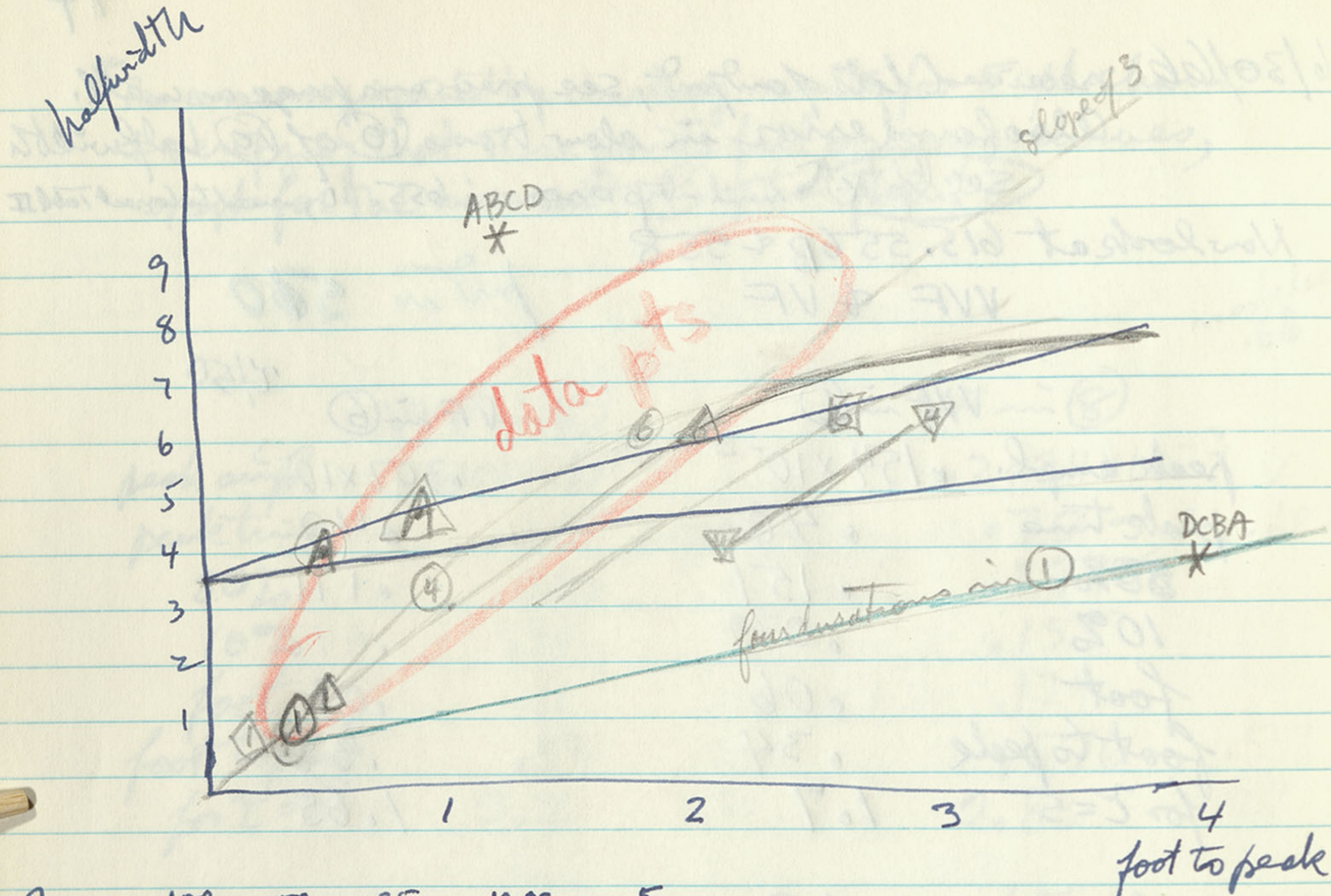
	VVF in (6)	VF in (6) 7/50
peak ampl.	$.154 \times 10^{-3}$	$.307 \times 10^{-3}$
peak time	.40	.40
~~50~~%	.151	.171
10%	.079	.092
foot	.06	.07
foot to peak	.34	.33
for $\tau = 5$	1.7	1.65
halfway down	1.3	1.29
half up	.15	.17
halfwidth	1.15	1.12
for $\tau = 5$	5.75	5.6

$\left(\frac{dV_F}{dt}\right) / V_p = 5.18$

Put in 615.801 two chains of five
one with ~~V~~F $\mathcal{E} = 0.1$ in (1) and (5)
other with $\mathcal{E} = 0.1$ in (1) (6) and $\mathcal{E} = 1.0$ in (5) (10)

615.802 single cpt. superimposing two $\mathcal{E}$ time courses.
$\mathcal{E} = 0.1$ with $\lambda = 50.$ VF
$\mathcal{E} = 0.2$ with $\lambda = 5.$ VS
↖ should have been 0.02

Meant

But will get

both interesting.



λ	100.	50.	25.	10.87	5.
	◇	○	△	□	▽
ε peak	.01	.02	.04	.092	.2
τ = 5 msec in MSEC	.05	.1	.2	.46	1.0

ink line corresp to square ε ⎍ of differnt durations to all compartments

Clearly, squareness is a positive disadvantage

green line corresp to ε ⎍ of differnd durations to (1)

Ojai ABCD approx time to peak = .25 τ ⟶ 1.25 msec
halfwidth ≈ 1.9 τ ⟶ 9.5

DCBA foot to peak ≃ .75 τ ≃ 3.75 msec
halfwidth ≃ .75 τ ≃ 3.75

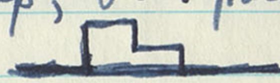
7/1/66

Taking stock of theoretical plot: halfwith [width at half amplitude] vs time to peak, including most recent additions. Need to decide whether paper needs two theoretical figures & also how best to arrange the presentation.

(A) falls into middle of range of data points
(F) anchors bottom end.
top end of data is well to left of slope 3 line.

* all of the E shapes in (8), (10) and (5) of fore have halfwidths between 7 & 7.6 and are too far to the right.

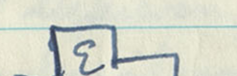
? How pull left? (1) Add proximal input

Also, probably can push up, but ? pull left by shaping E as follows 

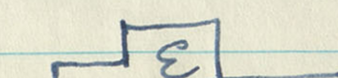
The (A) points, for uniform in all cpts, can account for only a small fraction (say 10%) of the data

To shift down, need emphasis of prox. location, faster E cannot help without spec'd shaping.

To shift up, need emphasis of periph location, slower E cannot help without special shaping.

But, expect that 

might push up

and that 

might push down

7/1/66

For varied duration in peripheral cpt., use square to simplify. Also, try shaping (for outer half) ~~inner half.~~

664.601 has square $\mathcal{E}=2.$ in 6, 7, 8, 9, 10 + 16 for $\Delta T = .05$

664.602 has [$\mathcal{E}=1.$ / .05] [$\mathcal{E}=.5$ / .1] same spatial dist., but changed temporal.

In summary, the (A) points, compared with data, prove that simple uniform dist. cannot account for observed range. This probably forces the need for spatial localization, but still must consider above shaped $\mathcal{E}$ to see what it can do.

Believe that extremes of expt. range require extremes of localization range, but need shift to left which probably means some temporal shaping.

Know for sure that spatio-temporal shaping of the ABCD type will give more than enough shift.

Note that increased temporal dispersion, without special shaping, does not help, in fact it makes it worse.

615.556 VS

peak = .90
foot = .165
foot to peak = .735
for τ=5 msec, 3.67

half down = 1.92
half up .416
half width = 1.504
for τ=5, 7.5

665.103 had an extra dependence card & did not run.

setup 615.503 VS all cpts.

615.505 VVF & VF in (5)

615.534 VVF in (4)

665.103 resubmitted

7/1/66

Got back four runs at 2:50

615.999

7/7/66 615.998 with 8, 9, 10 lopped off

see p. 12

This case has increasing weight of fast E in periphery

	615.999	615.998			
peak ampl	.0712	.05589			
peak time	.51	.32	1.08	half down	1.52^+
50%	.123	.0965	.096	half up	.12
10%	.035	.0301	.984	halfwidth	1.4
foot	.015	.0135	4.92	for $\tau=5$	7.0
foot to peak	.495	.3065			
for $\tau=5$	2.47	1.53			

This comes out between ⑥ & ⑧ slightly above the line.
i.e. too much peripheral weight

615.502 all cpts VVF $\lambda=100$.

peak time .065
foot ≈ .0025
foot to peak = .0625
for $\tau=5$, .312 msec

half down .77
half up .0156
.754
for $\tau=5$, 3.77 msec

which fits on my upper limiting line for uniform to all cpts.

615.510 VVF + VE in ⑩

peak = .80 − .17 foot
foot to peak = .63
for $\tau=5$, 3.15 msec

peak = .80 − .186 foot
foot to peak = .614
for $\tau=5$, 3.07 msec

halfwidth = 1.81 − .37
= 1.44
for $\tau=5$, 7.2 msec

halfwidth 1.83 − .388
= 1.442
for $\tau=5$, 7.2 msec

664.601 See p.18 Square $\varepsilon = 2.$ in 6, 7, 8, 9, 10 & 16 for $\Delta T = .05$

in 1

peak = .0186 at T = .63

50% at T ≃ .228

10% ≃ .11

foot ≃ .08

foot to peak .55

for τ = 5 μsec, get 2.75 μsec

halfdown 1.635

.228

1.407

τ_m = 5 7.035

in 16

.0929 .05

50% .024

10% ≃ .005

foot ≃ 0

foot to peak = .05

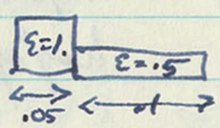
for τ = 5 μsec .25 ~~μsec~~

halfdown .744

half up .024

halfwidth .72

for τ = 5 μsec 3.6 μsec.

664.602 

in same pts as above

in 1

peak ≃ .0186 at T ≃ .66

50% at .268

10% at .135

foot .1

foot to peak .56

2.8

halfdown 1.68

− .27

1.41

τ_m = 5 7.05

shift slight

in 16

.0874 at T = .15

50% at .047

10% at .009

foot 0

foot to peak = .15

for τ = 5 μsec, .75 μsec

halfdown .842

halfup .047

halfwidth .795

for τ = 5 μsec, get 3.97

shift very slight.

7/5/66 Got back

615.801 sep.14 VF $\Sigma = 0.1$ in ① & ⑤ ; after T.C. $\Sigma = 0.1$ in ⑥ + $\Sigma = 1.0$ in ⑩

Here get double peak

peak $= .3577 \times 10^{-2}$ at .08 ; $.359 \times 10^{-2}$ at .08, and $.408 \times 10^{-2}$ at 0.7

50% ≈ .025 ; 50% at 1.72

10% ≃ .0075

foot ≃ .003

foot to peak = .077

for $\tau = 5$ μsec get .385 μsec

halfdown .32

half up .025

halfwidth .295

for $\tau = 5$ μsec get 1.47 μsec

compared with .285 & .915 for ① alone

i.e. this is up & nearly on the line.

615.802 single opt. with ~~two~~ ~~fine~~ course

peak = .065 at T = .65

50% .211

10% .048

foot .007

foot to peak ≃ .643

for $\tau = 5$ μsec, get 3.21 μsec

halfdown 1.63

halfup .21

halfwidth 1.42

for $\tau = 5$ μsec, get 7.1

Which is poorer than simple VF as expected because of error

See p. 14

Setup

615.803, like 801, but increase Σ to 0.2 in ⑤
~~& shift from ⑥ to ⑦ with $\Sigma = .2$~~
from ⑪ to ⑨ " $\Sigma = .4$

615.804, like 802, but reduce slow amplitude by factor of ten, as originally intended.

665.103 branchlet summation see pp 9-12

input resistance at (3) is .1248 cf. p. 184 book 8
×8 = 1.0
which is only half that at (4) or (9).
and that 1/3 that at (13)
1/4 " " (14)

peak in (1) is .03157 at T = .30
from 665.101 get 3,4,5 alone, here have 2&3 alone Sum

	at T = .25	T = .30	T = .35
3,4,5 alone	.011543	.013081	.01402
2&3 alone	.020928	.020235	.01903
Sum	.032471	.033316	.03305
cf combined.	.031037	.03157	.03114
Δ	.001434	.00275	.00191
	4.4% down	8.3% down	5.8% down

	T = .40	T = .45	T = .50
3,4,5 alone	.01454	.01478	.01483
2&3	.01771	.01646	.01536
Sum	.03225	.03124	.03019
combined	.03027	.02926	.02823
Δ	.00198	.00198	✓ .00196
	6.14% down		

3,4,5 gave .30 in (3) at 1.0
2&3 gave .20 in (3) at 1.0

In other words This gives 8% loss by nonlinear summation
while 665.102 gave 18% loss 3 gave .40 in (3) at 1.0

7/5/66 Also got back

7/50

615.505 (VVF) & VF in (5)

VVF		VF	
peak = .2108×10⁻³ at T = .30 ?		peak = .42×10⁻³ at T = .31	
50%	.111	50%	.131
10%	.057	10%	.07
foot	.045	foot	.055
foot to peak ≃	.255	foot to peak ≃	.255
for τ = 5 μsec,	1.27 μsec	for τ = 5 μsec,	1.27 μsec
halfdown	.995	halfdown	1.02
halfup	.111	halfup	0.131
halfwidth	.884	halfwidth	.89
for τ = 5 μsec	4.42 μsec	for τ = 5 μsec	4.45 μs

615.534 VVF in (4)		615.503 VS in all spts.	
peak = .3014×10⁻³ at T = .20		peak = .267 at T = .63	
50%	.0766	50%	.213
10%	.0375	10%	.072
foot	.028	foot	.037
foot to peak	.172	foot to peak	.593
for τ = 5 μsec, get	.86 μsec	for τ = 5 μsec	2.96 μsec
halfdown	.75-	halfdown	1.625
halfup	.08-	halfup	.213
halfwidth	.67	halfwidth	1.412
for τ = 5 μsec, get	3.35 μsec	for τ = 5 μsec, get	7.06 μsec

Setup 615.998 with (8), (9), (10) lopped off.

~~615.807~~ ~~sccpp27432~~

615.806

615.804 VF with $\varepsilon = .1$ (2.50) in single cpt. .1
VS (2=5) ε .02 " " " .01

	615.804	615.806
peak	$= .953 \times 10^{-2}$ at T = .54	.6492 at T = .44
50%	.064	.04
10%	.014	.011
foot	≈ .0015	.004
foot to peak ≃	.54	.436
$\tau_m = 5$ msec, get	2.7 msec	2.18 msec
halfdown	1.54	1.456
halfup	.064	.04
halfwidth	1.476	1.416
for $\tau_m = 8$ msec, get	7.38	7.08

approx 3× at large halfwidth

but could try for less VS to get leftwards.

Setup 615.806 with VS amplitude halved.

setup 615.80~~5~~ with combinations of .803

Setup 665.104 same as 103 but with temporal detail

7/6/66

In search of halfwidth / time to peak > 3

Look at Branchlet 665.103 .104

Rough because of large time steps.

time to peak ~~7~~ .30, .30 − .03 = .27

$\tau_m = 5$ → 1.5 msec (1.35)

half down ≃ 1.3 (1.285)

half up ≃ .12 (.109)

halfwidth ≃ .118 (1.176)

which is nearly 4 times

for $\tau_m = 5$, get 5.9 msec. (5.88)

Should redo with finer time steps

2 & 3

time to peak ≃ .25 → 1.25 msec

half down ≃ .85

half up ≃ .10

halfwidth ≃ .75 → 3.75 msec.

~~Got back~~ 615.803 — error missed at first

$\varepsilon = .1$ in ① ‖ $\varepsilon = .2$ in 7

$\varepsilon = .2$ in ⑤ ‖ $\varepsilon = .4$ in 9

~~peak = .366 × 10^{-2} at T = .08~~

~~50% .026~~

~~10% .008−~~

~~foot .003~~

~~foot to peak = .077~~

~~for $\tau_m = 5$, get .385 msec~~

~~half down .383~~

~~half up .026~~

~~halfwidth .357~~

for $\tau_m = 5$, get 1.785 msec

> 4X

~~.366 × 10^{-2} at T = .33~~

~~50% .08~~

~~10% .032~~

~~foot .02~~

~~foot to peak = .31~~

~~for $\tau_m = 5$, get 1.55 msec~~

~~half down 1.26~~

~~half up .08~~

~~halfwidth 1.18~~

~~for $\tau_m = 5$, get 5.9 msec~~

nearly 4 times

26

7/8/66

615.806 ~~VF Σ = .1~~ See p. 25

Try to shift forward 1.5 by 8
try rate constants 100.
& 2.5
in place of previous 50. & 5.

7/8/66 pd in for shifts.

615.815 correcting error in 805
Vfast Σ = .1 in ① & ②
.2 in ⑤

---

changed 2nd half to Slow Σ = .1 in ⑥ thru ⑩
VF Σ = .1 in ⑥ alone

615.807 single cpt. VVF 100. Σ = .1
VVVS 2.5 Σ = .01

615.997 Slow Σ = .01 in all lengths
Vfast Σ = .1 in ①

7/7/66

Got back 664.601 & 602 for longer times
See p. 21 for pencil entrées

* Result is that not much can be done with temporal shaping when input is only to peripheral half.

Got back 615.998 with 8, 9 & 10 lopped off of 615.999 (p. 20)
enter new values also on page 20
Came out between 5 & 6. ~~Not much gain~~.
No gain (in fact poorer) than simple uniform.
But at least not much worse than 5 or 6

error 20,15 missed

7/8/66 618.805 two chains of ⑤

ε = .1 in ①, ②
ε = .2 in ⑤

ε = .1 in ⑥
ε = .2 in ⑦
ε = .4 in ⑨

peak = .451 × 10^{-2} at T = 0.10
50% .029
10% .004
foot = 0
foot to peak ≃ .5 msec

half down .62
half up .029
halfwidth .591

~~foot to~~

halfwidth 2.95 msec

peak = .585 × 10^{-2} at T = .14
50% .035
10% .01
foot ≃ .005
foot to peak ≃ .135
for ε = 5, get .675 msec

half down .954
half up .035
halfwidth .919

or 4.595 msec

see p. 31 for 615.815

Many contemporary PDEq. problems can be done better by find the functional whose derivative yields the PDE. This can often be done most easily by going back to the original physical problem, and the derivation of the PDE.
There is a standard type of fcnal for Laplaces equation & variations thereof.

My be worthwhile to consider what functionals & what minimization is relevant to the nervous system.
? minimize error or cross-talk
? maximize resolution, information
? maximize stability, homeostasis.

Talk was very stimulating because well organized, with emphasis upon overall motivation & results.
To get this kind of stimulation, one needs either to give or produce a certain amount of such well focussed organization of material. Just as in a good lecture, also good research avoids too much muddling with side issues & trys to cut through to the essentials.

Relevant to Sabbatical. Might be well to go to a good applied math. research center, such as that one, or go somewhere where a good applied mathematician wants to work on a common problem.

7/8/66

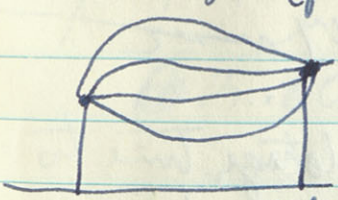
Interesting talk by Jose's friend Prof. Donald Greenspan
of Univ. Wisc. - Math. Res. Center

Improved - powerful numerical method for solving partial D.E. BV Problems.
for both linear & non-linear cases.

Method leans on
A. Functionals of classical calculus of variations
B. Conversion to algebraic problem
C. Solution by Generalized Newton's method.

Was a beautifully presented talk.

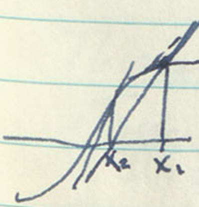
example of functional: suppose we wish to find $y(x)$, from $y(a)$ to $y(b)$, such that some integral (functional) has a minimum value.



$$\text{e.g.}\quad F = \int_a^b f(x, y, y')\,dx$$

classical method was to differentiate this to get a partial differential equation known as Euler's equation. Classical methods had a little more success with the PDE, than with direct work with the functional.

However, today, better to discretise the functional, and then proceed to solve the algebraic problem of solving for all partials set to zero; use generalized Newton's method for this solution, which converges well



Successive $x_j = x_i + w\left(\frac{f}{f'}\right)$ where if $w=1$, this is classical Newton

But generalized seeks w between 0 & 2 (0.5 & 1.9 in practice)
which can improve convergence.

615.815

$\lambda=50$, $\varepsilon=.1$ in ①, ② & .2 in ⑤

peak = $.465\times10^{-2}$ at T = .10

50% ≃ .03

10% ≃ .01

foot ≃ .004

foot to peak ≃ .096

or .48 msec

halfdown = .626

halfup = .03

halfwidth ≃ .596

or 2.98 msec

very similar to 615.805 which had faulty setup

change λ to 25

~~change in ⑤ to .4~~

do only 1 & 5 for all single speed

815B

$\lambda=50$, $\varepsilon=.1$ in ⑥,

$\lambda=10$, $\varepsilon=.1$ in 6, 7, 8, 9, 10

peak = $.2083\times10^{-1}$ at T = .38

50% ≃ .1

10% ≃ .021

foot ≃ 0

foot to peak = .38

or 1.9 msec

halfdown = 1.194

halfup .1

halfwidth 1.094

or 5.47 msec

This has six longer time to peak than does 805B

fast λ to 25.

change slow λ to 5.

change ε = .2 in ⑥

delete slow ε in 6, 7, 8

prod in 615.821

7/12/66

7/11/66 Wrote text accompanying Figs 1, 2 & 3 of joint paper.

discovered troublesome misplot of VF ①, foot to peak had been plotted wrong.

Put in 615.553 to get VF in ③
615.505B to get F & S in ⑤
to round out figure.

Did not yet get back those put in on 7/8/66 (see p. 27)

~~Wrote~~ Had 5 1/3 pages of typed text xeroxed.

7/12/66 got back 615.807, 615.815, 615.997 ↑ too many λ

615.807 single cpt. with VVF ($\lambda = 100.$) $\varepsilon = .1$
VVVS ($\lambda = 2.5$) $\varepsilon = .01$

peak $= .5916 \times 10^{-2}$ at $T = .96$
50% $\approx .15$
10% $\approx .008$
foot $\simeq 0$
foot to peak $= .96$
conc up to 4.8 msec

halfwidth not found

This case was too extreme.
Try fast $\lambda = 80.$ and $\varepsilon = .1$
slow $\lambda = 3.5$ and $\varepsilon = .0025$

615.808 put in

7/12/66

7/13/66

with fast dashed line & st. reference curve.

Then Fig. 2AB will be the experimental points.

and Fig. 3AB will be further theoretical points

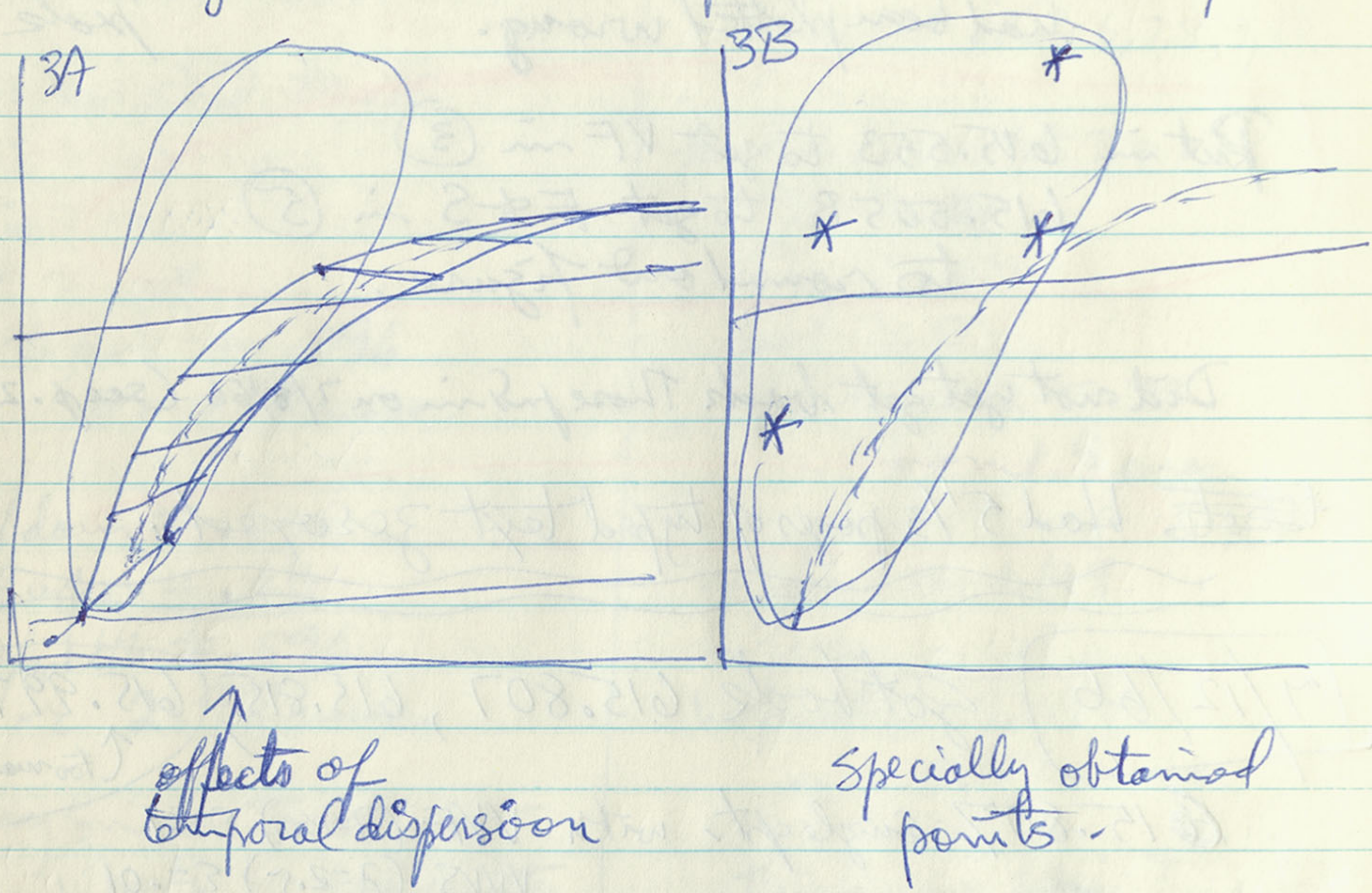


Fig. 3A will explore effects of fine course temporal dispersion only.

Fig. 3B will explore special combinations of fast + slow time course, or special combinations of locations.

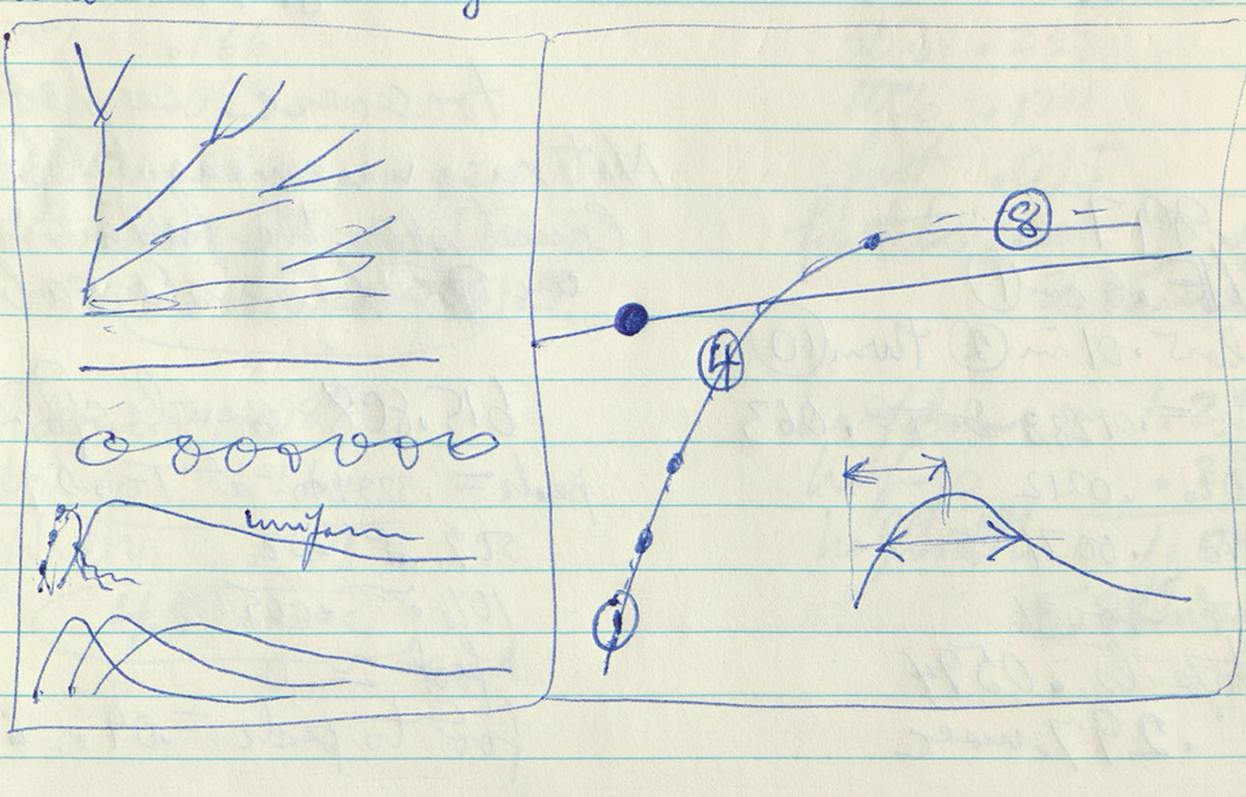
7/12/66

If the ones today don't fit well, I should try fitting procedure to get half up, peak, half down

Maybe, 7997 is fairly close, then pull out slow 2 add fast 2 & then let factor of ① & ② adjust, with the rest fixed.

Recorded 7/13/66

Spent afternoon talking with Phil & Bob re Phil's typescript of section IV & mine of section III. We noted several places to trim IV. They want III expanded. Then we concentrated on figures. Decided that Fig. 1 should be something like.



And that descriptive introduction be provided with the single series (original fast series), and the one straight reference line. Attempt to guide reader by the hand.

615.821 see p. 31
fast in ① & ⑤ of fwe

peak ≃ .612×10⁻² at ≃ .135
50% .046
10% .015
foot .0073
foot to peak ≃ .128
or .64 msec

half down .687
half up .046
half width .641
or 3.2 msec

see plot
has dip at T = .48

fast in ① of fwe
slow in ③④⑧⑤ of fwe

.1218 at T = .134
50% .046
10% .015
foot .007
foot to peak ≃ .127 or 8
or .635 to .64 msec

after dip
half down 1.74
half up .046
halfwidth 1.694
8.47 msec

too severe see plot
Note rise was same as at left.
Could slow the ~~fast~~ a bit
or speed the slow a bit

615.997
~~VF~~ F .5 in ①
slow .01 in ② thru ⑩

peak = .01288 at T = .063
50% .0212
10% .0071
foot .0036
foot to peak .0594
.297 msec

half down .25-
half up .02
halfwidth ≃ .23
1.15 msec
Dominated by fast

615.808 single cpt.
peak = $.3234 \times 10^{-2}$ at T = .09
50% at .02
10% at .005
foot ≃ .0
foot to peak = .09 or .45 msec

half down = 1.435
half up = .02
halfwidth 1.415
or 7.075 msec Too extreme

7/13/66 Got back five outputs

615.553 VF (50.) wired to (3)

peak = .8917 at T = .162
50% T = .0657
10% .0314
foot .023
foot to peak = .14
(or .7 msec)

halfdown = .565
halfup .066
halfwidth .499
or (2.495 msec)
2.5

good

615.505 fast (25.) & slow (10.87) wired to (5)

peak = .818 ×10⁻³ at ≈ T = .36 to .37
50% .166
10% .089
foot .07
foot to peak ≈ .29 to .30
or (1.45 msec to 1.5)

halfdown 1.085
halfup .166
halfwidth .918
(4.59 msec)
good

$.1706 \times 10^{-2}$ T ≅ .525
50% .239
10% .124
foot .095
foot to peak ≅ .43
(2.15 msec)

halfdown ~ 1.288
halfup .239
halfwidth 1.049
(5.245 msec)
good

setup 615.552 for VF in (2)

7/13/66 Errors the computations on previous page.

615.808 single cpt. was too extreme .45 by 7.08 msec
fast $\lambda = 80.$ @ .1, slow $\lambda = 3.5$ at .0025 also rather flat topped
Really need peak a little later and taller

However 615.806 was too mild 2.18 by 7.08 msec
fast $\lambda = 50.$ @ .1, slow $\lambda = 3.5$ at .01

~~for~~ T = t/τ	806	808	aim at
foot	.004	0	0
50%	.040	.02	.04
peak	.44	.09	.3
halfdown	1.456	1.435	1.5

i.e. try setting V = 0, .010, .05, .08, .09, .10, .08, .05
at T = 0, .010, .05, .10, .20, .30, 1.0, 1.5

Use initial estimate (for fast $\lambda = 50.$) $\varepsilon = .15$
(for slow $\lambda =$ ~~4~~ 3.5) $\varepsilon =$ ~~.004~~ .005

setup 615.809 to fit

615.822 make 1st five use slow trans in 1 & 5
make 2nd five use fast in (2), & slow in ~~3~~,4,5

615.552 noted previous page

615.996 FIT EPSP Shape
→ VF in (3)
~~Slow~~ Slow in 6,7,8,9,10

adjust this λ
& Kappa 1

615.951 fit Koppa ① & ε^{VF} in 3 (initially 10; ε initially .5; $\tau_{0,19}$)
to add to ~~slow~~ ε in ⑥ thru ⑩ (initially .01)

initially

peak = $.4456 \times 10^{-2}$ for T = .16
50% .066
10% .031
foot .022
foot to peak = .138
for τ = 5, get .69 msec

halfdown ≃ .718
halfup ≃ .066
halfwidth .652
for τ = 5, get 3.26 msec

finally K = 100. $\tau_{0,19}$ = .117

peak = .1066 at T = .17
50% at .064
10% at .031
.023
foot to peak = .147
for τ = 5, get .735

halfdown ≃ 1.51
halfup .064
halfwidth 1.446
for τ = 5, get 7.23

apparently the VF input was too fast.

Try fast (λ = 25.)

or could shift to another cpt!

7/15/66 Got back four computations

615.552 VF in (2)

peak = .1435 x10^-2 at T = .106 to .105

50% .041

10% .0175

foot ≈ .012

foot to peak ≈ .094 to .093

τ=5 gives .47 μsec

halfdown ≈ .37

halfup ≈ .041

halfwidth ≈ .33 .3295

τ=5 gives 1.65 μsec

615.809

single cpt. fit

need to correct

cord error

615.822

V slow trans in (1) & (5)

peak = .160 x10^-1 at ≈ .57

50% .174

10% .057

foot .018

foot to peak ≃ .55

for τ=5, get 2.75

halfdown 1.686

halfup .174

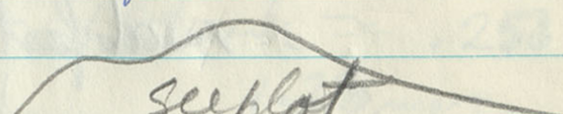
halfwidth 1.512

for τ=5, get 7.56

to far to the right

fast in (7) V slow in (9) & (10)

see p. 42 for setting up .822



see plot

rel. amplitudes wrong.

Put in 615.952 chain 1-10

615.953 chain 10

615.809 single cpt

all fit

Separate Kappa might have been better

both way

615.809 single cpt.

λ07 initially .15 .5 fast 50
λ09 " .005 .01 v slow 3.5

Initially		Finally	
.745 x10^{-2} at	.13	.2478	.125
50%	.031	50%	.0315
10%	.011	10%	.01
foot	.006	foot	.006
foot to peak =	.124	foot to peak	.120
	.62 msec		.60 msec
halfdown	1.366	halfdown	1.16
halfup	.031	halfup	.0315
halfwidth	1.335	halfwidth	1.1285
	6.675 msec		5.642

need fast to be rel. smaller than here
here 30 to 50 times
in .806 was only 10 times, not enough
suspect need about 20 times

call this 810 → The 809 run with Kappa may give this, because had λ0,9 set to .01 & λ0,7 free to adjust between .05 & .5

Could try 811 set this way

initially .15
gave ratio of 20 initially

try next with
λ = 25.

7/18/66

Setup 615.8~~23~~ A. fast $\lambda=25.$ $\mathcal{E}=.1$ in ①, $\mathcal{E}=.5$ in ⑤

(B. fast $\mathcal{E}=.5$ in ② ; ~~VS~~ $\lambda=5.$ $\mathcal{E}=.1$ in ⑨ & ⑩

May need another variation with slow instead of VS

Go back 615.953 fit — Kappa ① 25. initially
$\lambda_{0,19}$ for $\mathcal{E}$ in ③ fast $\mathcal{E}=.1$
$\lambda_{0,20}$ for $\mathcal{E}=$ ⑤ " $\mathcal{E}=.1$
with $\mathcal{E}=.01$ in 6, 8, 10 $\lambda=10.$

Kappa $= .1324$

A initially

peak $= .2424 \times 10^{-2}$ at $T=.29$

50% .111
10% .051
foot .036
foot to peak .254
1.27 usec

halfdown $=$ 1.023
halfup $=$ .111
halfwidth .912
4.56 usec

near uniform line

B after fit $\lambda_{0,19}=.0416$
$\lambda_{0,20}=.01$ .285

50% .103
10% .048
foot .034
foot to peak $=$ .25~~4~~1
1.2~~7~~6 usec

halfdown 1.35 est
halfup .103
halfwidth 1.247
6.235 usec

useful point

setup 954 with slow $\mathcal{E}=.01$ in ⑧, ⑨ & ⑩
slow $\mathcal{E}=$ adjustable in ⑤ initially .05
fast $\mathcal{E}=$ " in ③ initially .01

(See also p. 50)

Summarize Uniform Series.

					time to peak × halfwidth	
615.804	VF(λ=50.)	ε=.1	VS(λ=5.)	ε=.02	2.7 × 7.4	off to st.
615.806		.1		.01	2.18 × 7.08	good
615.808	(λ=80.)	.1	(λ=3.5)	.0025	.45 × 7.08	reject
615.809A	(λ=50.)	.15	"	.005	.62 × 6.68	?
615.809B	"	.5		.01	.60 × 5.64	?
615.811A	λ=50.	.2		.01	.86 × 6.35	*
615.811B		.08		.01	2.41 × 7.22	between 804 & 806
615.812		.15		.01	1.67 × 6.73	

note that 804, 806, 811A & 811B all fall on a line for ratios 5, 8, 10, 20

should try for 15

615.813	.175	.01	1.307 × 6.615	

Summarize Single input time course Series, several locations

615.999 fast (λ=25.) weighted for equal epsp components 2.47 × 7 *

615.803A,B, 804A,B were useful but contained error; now have 815A & 824

615.824A	λ=50.	ε=.1 in (1)		ε=.2 in (5)	.38 × 1.8 *
615.824B	"		ε=.1 in (2),	"	1.49 × 6.88 *
615.815A	"	.1 in (1)	.1 in (2),	.2 in (5)	.48 × 2.98 *
615.821A	λ=25.	ε=.1 in (1)		ε=.2 in (5)	.64 × 3.2 *
615.825B	"		ε=.1 in (2),	"	1.81 × 6.92
615.825A	"	ε=.1 in (1),	"	"	.8 × 3.68

7/19/66 Prepared summary of those shifted EPSP shapes. See pp 43 & 50
Discussed this afternoon with Bob Burke, to decide which ones to include in Fig. 3-B & discussion of paper.

* Point number (1), No need to shift to longer halfwidths, because these can be attributed to τ_m

(2) Agree that there may be some very small peripherally generated EPSP that follow theoretical curve but are experimentally lost in noise.

(3) Bob prefers to restrict to moderate rate constants. i.e. $\lambda = 50.$ & $\lambda = 25.$; leave out $\lambda = 5.$ or slower.

(4) For $\lambda = 50.$ & $\lambda = 25.$
Try somewhat similar to 615.803AB & 821A.
i.e. $\varepsilon = .1$ in (1) with $\varepsilon = .2$ in (5) or .1 in (4)+(5)
$\varepsilon = .1$ in (2) with $\varepsilon = .2$ in (5)
$\varepsilon = .1$ in (2) with $\varepsilon = .2$ in (4)
Suitable for simple presentation as a series.

already have 815A $\varepsilon = .1$ in (1) & (2) & .2 in (5)
∴ need first two above

615.824

615.811 Changes slow λ from 3.5 to 5. & initial ratio to 20.

615.955 $\lambda = 25.$ adjusted in both (1) & (3)
$\lambda = 10.$ in (8 9 & 10)

615.824 VF $\lambda=50.$

$\varepsilon = .1$ in ①
$\varepsilon = .2$ in ⑤

peak = $.37 \times 10^{-2}$ at T = .08
50% .026
10% .008
foot .0035
foot to peak ≃ .077 or .6
.38+ msec

halfdown = .385
halfup .026
halfwidth .359
1.795 msec

confirms .803

have plots

VF $\lambda=50.$

$\varepsilon = .1$ in ⑦
$\varepsilon = .2$ in ⑩

$.154 \times 10^{-2}$ at T = .315
50% .073
10% .029
foot .018
foot to peak = .297
1.485 msec

halfdown = 1.45
halfup = .073
halfwidth 1.377
6.885 msec

good, better than .803B

These fit together with 815A to make a good series, as anticipated.

Need to
Setup 615.825 A+B with $\lambda = 25.$

and $\varepsilon = .1$ in ①
$\varepsilon = .1$ in ②
$\varepsilon = .2$ in ⑤

~~ε~~
$\varepsilon = .1$ in ②
$\varepsilon = .2$ in ⑤

7/20/66 Got back four outputs

615.954 slow ε = .01 in ⑧, ⑨, ⑩ (10.)
slow ε = adjustable in ⑤ → initially .05 finally .026
fast ε = " in ③ (25.) → initially .01 .0052

Initially

peak = .10205 at T = .28
50% .099
10% .046
foot .033
foot to peak .247
1.235 msec

halfdown = 1.385
half up .099
halfwidth 1.286
6.43 msec

Finally (too delayed)

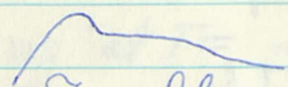
.10087 at T = .62
50% .106
10% ~.05
foot ~.036
foot to peak = .594
2.97 msec

halfdown = 1.705
half up = .106
halfwidth = 1.6
8 msec

but did succeed in getting long halfwidth

615.956 simulate only
with fast ε = .04 in ③
nothing in ⑤
same as before in 8, 9, 10

615.955 slow $\lambda = 10.$ with $\mathcal{E} = .01$ in (8910)
fast $\lambda = 25.$ in (1) initially .02 finally .0075
& (3) " .1 .02



Initially		Finally	
peak	T = .19+	peak	.175
50%	.0696	50%	.057
10%	.023	10%	.018
foot	.011	foot	.008
foot to peak	≈ .18	foot to peak	.167
	.9 μsec		.835 μsec
halfdown	.73	halfdown	1.49
halfup	.07	halfup	.06
halfboth	.66	halffoot	1.43
	3.3 μsec		7.15 μsec

below midline, too much near input

too much early peaking.
better without (1)

615.957

need something like .03 or .04 in (3)
compare .954 on previous page

$\mathcal{E}$ in (3) is .035

7/20/66

615.811 single cpt. VF (50.) + VS (5.) with original ratio of 20.
final ratio ~~18~~ 8.

Initially		Finally	
peak	$.1054 \times 10^{-1}$ dT = .175	peak	.486
50%	.033	50%	.045
10%	.010	10%	.012
foot	.004	foot	.004
foot to peak =	.171	foot to peak =	.482
	.855 msec		2.41 msec
halfdown	1.303	halfdown	1.488
halfup	.033	halfup	.045
halfwidth	1.27	halfwidth	1.443
	6.35 msec		7.215 msec

good

worse than 806

could try with ratio 15

also should try
with fast λ = 25.

615.812

note that 811 A, B, 806, 804
all fall on a straight line,
each has different ratios
of λ50 + λ5

∴ predict that dropping fast λ to 25
will give points on a lower line

615.952 adjusted for rate from 25. to 50. } in ③
amplitude from .2 to .115 }
with τ=10. (slow) ε=.01 in ⑥ — ⑩

Initially		Finally (early hump)	
peak	T=.23		.175
50%	.095		.063
10%	.045		.031
foot	.032	foot	.023
foot to peak	.198	foot to peak	.152
	.99 msec		.76 msec
half down	.88	half down	1.45
half up	.095	half up	-.06
half width	.785	half width	1.39
	3.925		6.95

see previous page for setup of 615.812
615.825
615.956
615.957

Seealso p.43

7/20/66 Summarize Combined input locations & time courses.
Some use fitting to try to get best fit.

615.815B	VF (λ=50.) ε=.1 in ①, Slow (λ=10.) ε=.01 in all five (too much slow)		1.9 × 5.47
615.951B	VF (50.) ε=.117 in ③, Slow ε=.01 in 6,7,8,9,10	(early hump)	.74 × 7.23
615.821B	fast (25.) ε=.2 in ①, Vslow (λ=5.) ε=.1 in ④ & ⑤,	(early hump & dip)	
615.952A	fast (25.) ε=.2 in ③, slow (10.) ε=.01 in 6,7,8,9,10		.99 × 3.925
615.952B	VF (50.) ε=.115 in ③, " "	(early hump) very similar to 951B	.76 × 6.95
615.953B	fast (25.) ε=.04 in ③, .01 in ⑤, slow (10.) ε=.01 in 6,8,10		1.26 × 6.24
615.954A	fast (25.) ε=.05 in ③, .01 in ⑤, slow (10.) ε=.01 in ⑧,9,10		1.235 × 6.43
615.954B	.026, .005, "		2.97 × 8
615.~~955~~ B	fast ε=.0075 in ①, .02 in ③, "		.835 × 7.15
.956 try	fast (25.) ε=.04 in ③, nothing in ⑤, "		1.04 × 6.66
.957	.035		1.04 × 7.15
also try	VF ε= in ⑤ " "		
.958	⊗ .03 in ③ "		1.04 × 7.74
.959	⊗ .04 in ④ "		2.7 × 7.86

↑ in final figure

615.825 fast $\lambda = 25.$

$\varepsilon = .1$ mi (1)
$\varepsilon = .1$ mi (2)
$\varepsilon = .2$ mi (5)

ε
$\varepsilon = .1$ mi (7) $\simeq$ (2)
$\varepsilon = .2$ mi (10) $\simeq$ (5)

peak $T = .17-$
50% .054
10% .018
foot .009
foot to peak $\simeq$ .16
.8 msec

halfdown .79
halfup .054
halfwidth .736
3.68 msec

peak $T = .39+$
.11
.045+
foot .03-
foot to peak .362
1.81 msec

halfdown 1.494
halfup .11
halfwidth 1.384
6.92 msec

Could try 615.813 with factor 17.5 ✓
~~615.828 fast λ=25, with ε=~~
615.958 fast $\varepsilon = .03$ mi (3) ✓
615.959 fast $\varepsilon = .04$ mi (4) ✓

late 7/22/66

7/22/66 got back four outputs

615.956 | .03 in (3) | .04 in (4) | 615.957

fast $\mathcal{E}$ = .04 in (3) (25) | fast $\mathcal{E}$ = .035 in (3) (25.)

slow $\mathcal{E}$ = .01 in (8), (9), (10) | slow $\mathcal{E}$ = .01 in (8) 9 10

	615.956			615.957
peak ($.6735 \times 10^{-3}$) T =	.24	.24	.59	($.5914 \times 10^{-3}$) .24
50%	.0954	.095	.14	.0954
10%	.0445			.045
foot	.032			.0325
foot to peak	.208			.208
	1.04 usec			1.04 usec
half down	1.427	1.66	1.71	1.525
half up	.095		.14	.095
half width	1.332		1.57	1.430
	6.66 usec		7.85	7.15 usec

615.812 single cpt. VF $\mathcal{E}$ = .15 (50.), VS = .01 (5.)

peak $.838 \times 10^{-2}$ at T = .34

50% .035

10% .011

foot .005

foot to peak = .335

1.675 usec

half down 1.38

half up .035

half width 1.345

6.725 usec

8/4/66

6/5.960 Sep.56

7/28/66

worked on Fig. 4 & text of joint paper for several days.
Also seminar on fcnal analysis (Banach Spaces)
Got back some computations on 7/26/

615.813 single cpt. VF amplitude 17.5 x VS amplitude

peak at T = .27
50% .021
10% .011
foot .0085
foot to peak ≃ .2615
1.307 msec

halfdown 1.344
halfup .021
halfwd 1.323
6.615 msec

615.958 fast ε = .03 mi (3)
slow ε = .01 mi (8) (9) (10)

peak .24
50% .093
10% .045
foot .033
foot to peak .207
1.035 msec

halfdown 1.64
halfup .093
halfwd 1.547

7.735 msec

615.959 fast ε = .04 mi (4)
ε = .01 mi (8), (9), (10)

peak = .59
50% .138
10% .069
foot .05
foot to peak = .54
2.7 msec

halfdown = 1.71
halfup .138
halfwidth 1.572

7.86 msec

8/2/66

Test idea that hyperpolarizing current will have significantly more effect upon rising slope than upon peak of EPSP having both near & far input location.

near input would have most effect on rising phase
far " could " " " " peak

Try with 615.825 → 615.826

and with 615.958 → 615.960

Hope that this may account for a fair bit of the discrepancy that others (Phil) have emphasized. (as well as Eccles in 1961 paper, & Tom Smith)

Previously I found that for any single location, both slope & peak were ~~increased~~ by same factor, which is the factor ~~of~~ driving pot. change at perturbed site

Perhaps should also do for the "impedance" study
Note: components out of phase

Earlier today, talked with Bob (Burke) & gave him dittos of first ten pages of Joint ~~text~~ & first two pages of Part II. He would like me to outline ~~text~~ for Fig. 4 & will tackle rest.

Today I got off letters to Arbib, Cochran & Plonsey & Tsukahara, Mannen, Ramon-Moliner

615.960 like 615.958 but with I.C. for T=1.0 of current step

at T=0.24 Summer 20 has .01814
which was diff. from .29992
value in (1) .31806
Whereas control step value .31764
apparent EPSP .00042

compared with control EPSP peak = .00050925 at this time

i.e. EPSP is reduced nearly 20%
but step ~~[illegible]~~ is distorted only ~ .13% for conductance that gives .05% of driving pot.

may need to rerun without E_E battery

826A in (1) 826B in (6)

(11)	.019356	(16)	.02904
	.266367		.26637
(1)	.285723	(6)	.29541
control step	.2795	control step	.2928
apparent EPSP	.0062	apparent EPSP	.0026

control EPSP .00826 control EPSP .00306

8/4/66

Got back 615.826 & 615.960

Realized that these I.C. are for $T = 1.0$ rather than for St. St.
But these results can be useful for the % distortion story, by using the older controls for unperturbed case with these initial conditions.
Must refer back to earlier series for this.

Now, setup 615.827 & 615.961 with true St. St. Initial conditions. taken from 646. series & 652.003

really want to compare rising slope & peak

rel amount rect. story

← this more incidental re detectability story.

Telephone call from Tunturi

he is beginning to think of pop response in terms of units & that neighboring units might not be doing the same. ~~E~~

~~Bay~~ He asked if current from one dendrite could flow to neighbor.

8/5/66
Got off 4 pages on Fig. 4 for Bob Burke.

Also did calc comp. 57, but next output
did not yet come back.

8/30/66
Back from vacation
Rt. Hand in Cast. Handwriting poor

Check output

615.961 in (20) ≡ trans rel to st. st.

(early) peak = .44309 × 10^{-3} at T = .24

slope at .09 to .10 is $\frac{.036517 \times 10^{-3}}{.01}$ = .003652

compare 615.958 peak = .509254 × 10^{-3} at T = .24

slope at .09 to .10 is $\frac{.041989 \times 10^{-3}}{.01}$ = .0042

Driving Pot. in .961 was initially reduced by 18.9% in (1)
15.6% in (2)
13% in (3)

peak 87% of control (443/509) →

slope also 87% of control ∴ no separation of peak & slope in this case

	st.st. relaxation	
1	17.2%	→ 20
2	12%	14
3	8.6%	10
4	6.6%	7.7
5	5.7%	6.6

peak shifted less than slope but separation is less than I had hoped.

Might work better if use smaller close input & bigger middle input. So that close input affects mainly slope rather than peak

8/30/66

in (11)

615.827 peak = .69745 × 10^{-2} at T = .17

.05 to .06 slope

.3855 × 10^{-2}
.3123 × 10^{-2}
.0732 × 10^{-2} / .01 = .0732

84.4%

Compound .825 .82629 × 10^{-2}
Control

slope

~~.5700 .462 × 10^{-2}~~
~~.3710 × 10^{-2}~~
~~.078~~ ~~94%~~

.462
.375
.087 84%

(16) peak = .2746 × 10^{-2} at T = .42 89.7%

slope .10 to .11

.1355 × 10^{-2}
.1185 × 10^{-2}
.0170 × 10^{-2}

Compound .825
Control

~~peak~~ = .3061 × 10^{-2} at T = .42

.15376
.13452
.01924 × 10^{-2} 88.3%

add
rates of rise
synaptic resistance

Part I – B evoked reward
? C ~~functional sig~~
of localized – esp. re
linearity of summation
esp. my paper

Part II add my two introductory pages
add ¶ on operational distinction
Phil's text on circuit diagram should
be qualified as meant for faster EPSP
proxi somatic input, because
dendritic inputs make mechanisms
indistinguishable.

(emphasis)

→ only operational electric distinction

? whether to add equations & or numerical
examples to Part II

8/31/66

Going over typescript from Phil & Bob

9/1 & 9/2/66

Talked with Phil about joint manuscript

Noted some improvements.

Decided to check shape index plot ① ④ ⑥ ⑧
for Z_m = 1.0 & Z_m = 4.0

Expect { improved half width vs time to peak
with Z_m = 1.0 because of smaller ↑

poorer course with Z_m = 4.0 because
of longer time to peak.

possibly also compare half width & t.t. peak for ④ (Z = 1.2) of Z_m = 4.0
& ⑦ (Z = 1.2) of Z_m = 2.0

expect same time to peak
and expect half width shorter for ④ of Z_m = 4.0
because prox. half.

X Should give top priority to completing
my own paper with above & also discussion
of rates of rise vs. peak amplitude

Perhaps best expressed as ratio.

SAAM program at NIH, while Marj is away
can consult Curt Huntington Bldg 12 Rm 2204
Ext 6-4727

Need plain buff decks

9/2/66 Roger Nicoll gave noon Seminar at Wade Marshall's Lab. → asked me to come
I phoned Reese & Brightman

He accepts & obtains further confirmation of dendrodendritic pathway, esp. evidence that Mitral blocked during its inhib.
also ~~[illegible]~~ blocks this inhib. pathway.

~~However~~, he claims that he records from two kinds of cells in granule layer. Those which fire to LOT have cell bodies immediately below MBL & do not get more ~~when~~ 2nd LOT goes in during mitral inhibition. Others which appear to receive deep input which he believes comes from collaterals of Tufted cells in Ant. Comm fibers.

He also pointed to P_2, 2nd positivity of the 2nd neg (surface) & claimed that this was generated by the ~~hyper~~pol. gradient of mitral cells produced by inhib. from granule cells.

He tried to use this as index of when ~~[illegible]~~ input failed to elicit inhib. from granule cells.

Must let Gordon Shepherd know.

615.831

for NIH run

~~setup~~

mod of 615.827

Two chains of 15

1st hyperpol in 6–10

Both chains have ε = .1 in (1)
.3 in (4)

also ~~medium~~ mpd

$\lambda = \tau/25$

Need to duplicate decks

for (1) in $\tau_m = 2$ need time to

expect peak ≈ .58 t/τ

halfdown ≈ 2.0 t/τ

maybe use $\frac{1}{200.}$ .01 40.

$\frac{1}{200.}$ .42 .02 80.

use T. change & no plotting.

9/5/66 ~~Memorial~~ Labor day

Clear day to set up fresh decks to test — (plain buff cards)

(A) time to peak & half width for $Z_m = 1.0$

see p. 64, see p. 6 (615.042 also 6/28/66)

& p. 169 of book 8

615.102, .104
615.012
.013
.014

compare (7) [(9)] of $Z_m = 2.$ with (4) [(5)] of $Z_m = 4$
" " " " = 1. " " " $Z_m = 2.$

also, get (1), (5), (7), (9) with $Z_m = 1.0$

But do with ~~fast~~ $\lambda = \tau/50.$ .971 .972

however, already have some with medium $\lambda = \tau/25.$

Today plotted values from p. 169 of book 8 with control
It can be seen that $Z_m = 4$ increases time to peak too much
while $Z_m = 1.0$ produces no improvement over range, $Z = 0$ to $Z = 1.$
& is confined ~~below~~ below straight reference line.

but see p. 76

9/6/66 PM talked with Larry Goldman.

got back 9/8/66

615.831

hyperpol

(1) | (16)

(1) peak = .6354×10^{-2} at T = .15 | .7412×10^{-2} T = .15

57% .0475 | .0475

≈50% up .338 at T = .05 | .396 at T = .05

10% .015 | 10% ≈ .015

foot ≈ .006 to .007

≈ half down 1.04 | half down .995

half up .0475 | half up .0475

halfwidth .9925 | .9475

slightly less with hyperpol

slope at .04 to .05

.3379 | .3959

.2586 | .3029

.0793 | .0930 slope

slope ratio = 1.173

peak ratio = 1.167

Driving pot ratio in (1) was 1.172

(4) 1.066

∴ Add as much ... to 3

to try to get later peak

.832

see p. 74

9/6 & 9/7/66

Duplicated decks on plain buff cards
prepared to be put into NIH production run 9/7 night

running time

1.54 615.831 Two chains of five with same ε, one hyperpol.
ε = .1 in ①, ε = .3 in ④ ... 25 med τ/25
hope to separate slope & peak

1.21 615.971 ε = .1 in ⑦ of Zm = 2. }
1.75 615.972 " ④ 4. } fast τ/50
4.50 min

for ⑦ of Zm = 2. | for ④ of Zm = 4.

	⑦ of Zm = 2.	④ of Zm = 4.
peak =	$.2389 \times 10^{-3}$ at T = .545	$= .3885 \times 10^{-3}$ at T = .535
50% up at	.2206	.2203
10%	.12	.1085
foot	.095	.081
foot to peak =	.45 (2.25 msec)	.454 (2.27 msec)
half down =	1.53	1.367
half up	.22	.22
half width	1.31 (6.55 msec)	1.147 (5.73 msec)
	Ratio = 2.92	Ratio 2.53

This is sig less
12½%

615.973 make Zm = 1.0

615.974 make Zm = 2.0

see p. 76

In Q.M., there is an essential difference usually embodied in uncertainty principle.

Let "states" be definite & unambiguous (but ψ^2 defines a probability)

Then observable is not uniquely predicted. Several answers possible & there is a prob. dist. over those.

He gave an artificial example where states are defined as points on a unit sphere, and observables are 3X3 matrices. The prob dist obtained as an inner product of matrix A with state.

& Evans say matrix A, is already product of a state variable & Ψ fn.

Prof. V. says there is an important sense in which Q.M. represents one logical extreme for all possible logics of observables, while classical mechanics is the other extreme. Statistical mechanics lies between.

His book on all this is in press. He gave some other references.

9/7/66

Prof. V gave a good lecture (introduced by Evans)

NIAMD-MR Seminar. Axiomatic foundations of quantum mechanics. Speaker: Prof. V. S. Varadarajan, Dept. of Mathematics, UCLA, Los Angeles, Calif. Bg. 31, Conf. Rm. 4.

Axiomatic approach has special appeal to mathematicians, who do not share the physical intuition & jargon of physicists.

Kernel of axiomatic approach is in Dirac

But foundations & current work stem from Von Neumann.

Having been done for Q.M., was done also for classical mechanics & can now have math versions of uncertainty, complementarity, etc.

Classical Mechanics, needs three main things defined

1. Physical law (gravitation, e.m., etc potential fam)
2. State of System
3. Observables

Classical mechanics of single particle: state defined by six numbers i.e. a six dimensional vector (three space coords. & three momentum coords.)

An observable is some function of the state.

e.g. kinetic energy is fcn of three momenta
pot energy " " " " space coordinates
other observables may be fcns of all six

(given the state at some time) + 1., all states, future & past can be computed. All completely determined.

For any given state, observables can be computed.

615.832

(1)

peak I = .34
50% ≃ .066
10% ≃ .02
foot ≃ .009
foot to peak ≃ .33

half down ≃ 1.24
up .066
1.174

which is in exp. range

(16)

.325
.063
.02
foot .01
foot to peak ≃ .315

half down ≃ 1.213
.063
1.15

which is in exp range

setup 615.833

ε = .1 m (1)
ε = .4 m (4)
ε = .5 m (5)

in future, try ε in all five

i.e. peak ~~slope~~ increased by same % as driving pot in (1)

peak ampl. increased only 2/3 of this %

9/9/66 Got back three computer runs.

615.832 ε = .1 in (1) } two claims of five
ε = .3 in (3) & (4) } 2nd claim hyperpol.
615.833 in red with .4 in (4), .5 in (5) and .1 in (1)

peak in (1) = .9365 × 10^{-2} at T = .34
.8473 at T = .64

peak in (16) = 1.045 × 10^{-2} at T = .325
.9203 at T = .625

peak ratio = 1.117 i.e. less than 12%
1.087 less than 9%

Slopes

T	in (1)		in (16)		ratio
.07	.4937	.4694	.5761	.5497	
.06	.4245	.4090	.4959	.4790	1.172
	.0692	.0604	.0802	.0707	1.16
				.4790	
.06	.4245	.4090	.4959	.3962	.0828
.05	.3470	.3382	.4058	.3030	
	.0775	.0708	.0901	.0932	1.164
.05	.3470	.3382	.4058	.3030	1.17
.04	.2629	.2586	.3077	.2041	1.17
	.0841	.0796	.0981	.0989	1.167
					1.172

see p. 80

i.e. here get 17% increase of peak slope agreeing with hyperpolat (1)

and get < 12% increase of peak value

Setup 615.975 & 976

Zm = 1.0

Expts 5 + 6

to see how related to

st. reference line

615.975

peak = .5085 $\times 10^{-3}$ at T = .15
50% .062
10% .032
foot .025
foot to peak .125 .625 mm

halfdown .80
halfup .062

halfwidth .74 3.7 mm

615.976

.4266 at T = .21
50% .077
10% .0405
foot .031
foot to peak .18 .9 mm

halfdown .975
halfup .077

halfwidth .90 4.5 mm

9/9/66 fast (τ/50)

615.973	615.974
Ε = ɑ lin ⑦, Z_m = 1.0	E_m = ɑ lin ④, Z_m = 2.
peak = .3887 ×10⁻³ at T = .28	.5965 ×10⁻³ at T = .23
50% .099	50% .095
10% .051	10% .049
foot .04	foot .037
foot to peak = .24 (1.2 mm)	foot to peak = .193 (.965 mm)
half down = 1.07	half down = .78
up .099	.095
half w. .971 (4.85 mm) ratio 4.05	ratio 3.55 .685 (3.425 mm)

This is above st. reference line and to left of dashed line. slightly left & up from ◇5

agrees with 615.554 p.3

Actually, both ⑦ & ⑩ of Z_m = 1.0 lie very close to the straight reference line, between ▲ and ■

Can use for text.

Conclude that Z_m = 4. definitely worse
time to peak too long for halfwidths

Z_m = 1.0 improves ratio, but halfwidths do not exceed τ ∴ cannot account for longer halfwidths with [illegible]

9/12/66 got back output, but did not have time to go over because of Wade Marshall's seminar on cortical potentials with Arnie Towe & Chuck Woody.

Took most of the day.

Towe: M & S neurons are two functionally distinguishable subpopulations (cat forepaw stimulation)

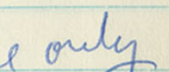
S respond only to contralateral stim

M " to both " & ipsilateral

Also, M is knocked out by nembutal but not by chloralose, which they use.

His subtraction of M field from S field is admittedly an approx.

* I found that I was temporarily under a misconception. (? maybe not) I thought he superposed current contributions for each spike, but actually, he does it for each neuron which generates a spike train! However, the S neurons (on which he concentrates) often fire only once, or very briefly. But he believes that he is dealing with the synaptic potentials (slow) which generate the spike train. (He could be mistaken, because of the brevity of the S trains).

Anyhow, the time function he puts in his matrix, he regards as a slow synaptic potential. If he really did this for a very long spike train, I might agree to this possibility, but because of only one or a few spikes, I guess it may be spike current after all, but must examine time scale of his diphasic  which he calls epsp & ipsp.

Busy, hodsenup week
Udo had cataract operation
Paul ~~Fatt~~ gave seminar
Math seminars.
Also primary elections
biggest rainfall in 4 years, water in basement.

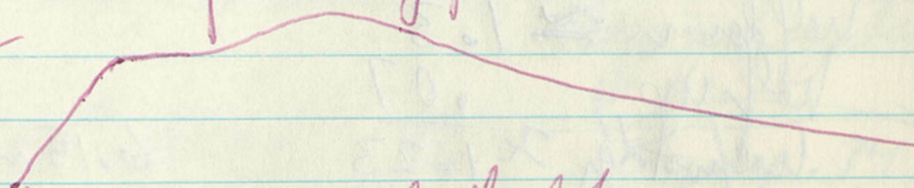
Anyhow, Udo's eye seems to be doing fine as of 9/16/66

Did reprint filing during odd moments because not in mood to edit or write.

9/13/66 computer output 615.833 entered in red p. 74

here slope increased by 17.2%
peak " by 8.7% (half as much)

but this case is probably pushed a little too far



Except on fast sweep, may look like some of Bob's results.

~~Check time to peak & halfwidth~~ does not get half down

615.975 & 615.976 see p. 75

Setup 615.834 with 3 & 4
615.977 in (1)
.978 in (3)

peak ≈ .38
halfup ≈ .07
10% ≈ .02+
foot ≈ .01
foot to peak ≈ .37 1.85 msec

halfdown ≈ 1.3
halfup .07
halfwidth ≈ 1.23 6.15 msec

615.977
ε = ①, $Z_m = 1$, $\lambda = \tau/50$

peak = $.1528 \times 10^{-2}$ at T = .05
50% up .018
10% .004
foot ≈ 0
foot to peak = .05
.25 msec

halfdown ≈ .17+
halfup .018
halfwidth .153
.765 msec

615.978
ε = ③, $Z_m = 1$, $\lambda = \tau/50$

$.83 \times 10^{-3}$ at T = .09
50% .037
10% .011
foot ≈ .011
foot to peak ≈ .08
.4 msec

halfdown .367
halfup .037
halfwidth .330
1.65 msec

9/16/66

615.977
.978

615.834 $\varepsilon = .1$ in (1)
$\varepsilon = .3$ in (3)
$\varepsilon = .4$ in (4)
(of 5)

} this gives a good epsp shape. better than 833.

(1) control, (16) monitors transient in (6) with st. st. hyperpolarization

(1) peak = $.9979 \times 10^{-2}$ at T = .38

(compare p. 74 + 69)

(16) " = 1.107×10^{-2} at T = .36

Ratio = 1.109   increase is 10.9% < 11%

	(1)	(16)	Ratio
T=.06	.4249	.4963	
.05	.3472	.4060	
Δ =	.0777	.0903	
T=.05	.3472	.4060	1.17
.04	.2630	.3078	1.17
Δ =	.0842	.0982	1.167

slope increase is ≈ 17%

X This seems to be the partial separation that is compatible with a reasonable epsp shape with near & far synaptic loci.

See shape at left

one can say how much is due to each E locus & then use these rel. values as weights for the factor of hyperpol. in a weighted mean of factors.

e.g. suppose the contributions were equal in 615.834
then would have .172
.085
.066
3 | .323
.108 → 10.8
which is close to 10.9% peak increase obtained in this case.

Similarly, if contributions were equal in 615.833, get .172
.066
.057
3 | .295
.098 → 9.8% whereas 8.7% was observed
Presumably at this late peak, contribution of (1) was slightly less than equal

Probably should yet do the case where all compartments have E { (a) weighted .1, .2, .3, .4, .5
(b) all equal

more important, but may already have? Probably only at T = 1.0 not for st.st. hyperpol.

Setup
615.835
615.836

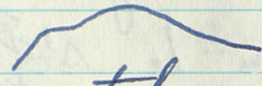
Consolidate

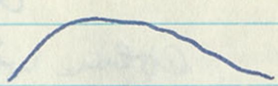
9/21/66

Hand is much better
wrote several letters yesterday

Today get back to work on EPSP papers.
Will see Phil Nelson ~~today~~ to show him the results of the second calculations.

Now time to summarize what, from these ↑ should be incorporated into the papers.

Ask Phil if 615.833  is within his experimental range { slope increase 17.2%, peak " 8.7% }

whereas 615.834  { slope increase 17%, peak " 10.9% }

Show these two to Phil. I can probably get something between those two, but it is probably not worth the extra bother.

* The conclusion is this: When E is at a single locus, whatever the locus, then hyperpol. causes the same proportionate increase in slope & peak & this is given by the increase of effective driving potential at the locus; this I found out long ago with the earlier hyperpol. runs.

But, with several E loci, this is no longer true, esp. if the peripheral loci are responsible for a significant delay of peak. Then, slope is dominated by increased driving pot. at near locus, but peak increase is compromise (weights depend upon electrotonic decrement of hyperpol and rel. E values) see left. Presumably, at peak time,

If compare (4) of $Z_m = 2.$
with (7) of $Z_m = 1.$ both time to peak + halfwidths are longer
(see p. 76) ← This does give a larger $\frac{\text{halfwidth}}{\text{time to peak}}$ ratio
4.05
compared with 3.55

But halfwidth only barely exceeds straight reference line. ∴ $Z_m = 1.$ shifts to left but does not extend far enough out to account for the data.
even with $\tau_m = 7$

Conclusion is that $Z_m = 1.0$ is too short to account for the larger halfwidths, unless ~~one were~~ to do very special diddling with E time courses. That $Z_m = 4.0$ fits sig. less well than $Z_m = 2.0$ & furthermore, $Z_m = 2.0$ can get us into the exp range of halfwidths, esp. with several loci.

Note; This has to be in joint paper because my own paper is not so specific about motoneuron.

9/21/66

∴ Need to write a section for my paper on the effects of Steady hyperpolarizing current upon EPSP shape!

A. Single locus { many expts easily summarized ~~provided E is small enough for linear range~~ } don't even need this proviso because everything proportional to driving pot.; for large E get same non-linearity for several different driving pots.

B. Several loci
near locus dominates slope
far locus ~~effects~~ contributes to peak.

C. All loci { uniform (least arbitrary) / graded }

This affects Tom Smith's paper & Phil Nelson's paper.

\# ~~Need~~ to write section for joint paper which deals with effect of $Z_m = 4.0$ & $Z_m = 1.0$

$Z_m = 4.0$ makes all time to peak & halfwidths longer.

however, slope of shape index plot is shifted to right

& comparing (4) of $Z_m = 4.$ i.e. $3 \times (.4) = \Delta Z = 1.2$

with (7) of $Z_m = 2.$ i.e. $6 \times (.2) = \Delta Z = 1.2$

gives same time to peak, but shorter halfwidth because max half.

This is in wrong direction in attempts to fit data.

Note that present steady state hyperpol

17.178% ⟶ 20%
11.93% ⟶ 13.9%
8.58% ⟶ 10%
6.61% ⟶ 7.7%
5.7% ⟶ 6.64%

factor 1.165
would increase current I from 0.5 to 0.5825 for hyperpol current

Whereas compute $V/V_0 = \cosh(Z_m - Z)/\cosh Z_m$

for 10 cpts, $Z_m = 1.8$, $\Delta Z_m = 0.2$, get

Z	Z_m-Z	cosh(Z_m-Z)	V/V_0	e.g.
0	1.8	3.107	1.0	20%
.2	1.6	2.577	.828	
.4	1.4	2.151	.692	13.8%
.6	1.2	1.811	.583	
.8	1.0	1.543	.496	9.9%
1.0	0.8	1.337	.430	
1.2	0.6	1.185	.381	7.6%
1.4	0.4	1.081	.348	
1.6	0.2	1.020	.328	6.6%
1.8	0	1.0	.322	

These agree rather well with above.

In fact, they agree better than five steps of 0.4 presumably lumping trouble

0	1.6	2.577	1.0	20%
.4	1.2	1.811	.704	14.1%
.8	.8	1.337	.52	10.4%
1.2	.4	1.081	.42	8.4%
1.6	0	1.0	.389	7.8%

} not quite as good

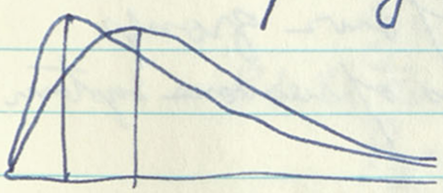
~~seems~~ That Z_m of 1.6 is too low for this case

9/23/66

Yesterday saw Phil & also started to write section on effect of hyperpol. current.

Think it may be useful to prepare a figure based on new calcs. where 20% hyperpol at soma, and use (1) & (4) of five chain
Show (1) & (4) seperately with & without hyperpol
& show them ~~together~~ " & " "

Only uncertainty is rel. mag.
~~comparing~~ One clue is that Phil has



control time to peak ≃ 1.25 msec
& hyperpol ≃ .6 "
i.e. cut to one half.

∴ I need a compromise between .831, 2, 3, 4
where the 20% may help a little.

Try ε = 0.1 in (1) with ε = 0.6 in (4)

because 0.3 in (4) was too little in .831
0.3 in (3) & (4) was pretty good .832
0.4 in (4) & 0.5 in (5) was too much in .833 (& too late)
0.3 in (3) + 0.4 in (4) was pretty good in .834
but not enough shift of peak

On 10/6/66

Dr. Martin A. GARSTENS
ONR Physics Branch
Code 421
Wash. D.C. 20360

OX-6-1890

visited at N.I.H.

George Weiss }
Marvin Zelen } who sent him to see us.

Mones & I talked with him –

He is interested in supporting biomathematics.

did not know of our group
→ & biophysics of nervous system

He has met Livingston
Elsasser
F.O. Schmidt's meetings in Boston
?Gerard?.

Code 213 phoned 10/14/66 90

SY-5-5971

9/23/66 Date ≈ Dec 6&7 ± 1

Yesterday had phone call from James Garvey of ONR, Pasadena

Setting up small invitational seminar suggested by Robert Stewart on Cellular Electrodynamics & plasticity in grey matter.

Stewart is giving a USC seminar on "design for a cortex" based on some of his earlier studies.

He want's group to see his hardware at USC & discuss related implications

Other people being asked include

Seth K. ~~Sharples~~ (at ~~Einstein~~ Pharmacology & Logic) – (Habituation 1964 Ann. Rev. Physiol. Use & Disuse etc)

Gerard

E.L. Ed Bennett (Berkely Chemical Biodynamics – recent article in Science Aug 5 ?)

Purpura, who is joining Sharpless

Ranck

Morrell

in Nov. or Dec., for two days: Emphasis on discussion rather than publication of papers, but there probably will be some sort of publication.

I could give dendro-dendritic story.

?: epsp or dendrites in field.

If Stewart is ~~pumping~~ pushing idea of fields guiding dendritic growth which is what I suspect, then it seems likely to be much to non-specific to have much informational significance.

$\mathcal{E} = .1$ in ① & ⑥
.2 in ② & ⑦
.3 in ③ & ⑧
.4 in ④ & ⑨
.5 in ⑤ & ⑩

Here medium 4/25

615.836

① control ⑯ with hyperpol

peak

$.1637 \times 10^{-1}$ at $T = .405$ $.1810 \times 10^{-1}$ at $T = .385$

peak ratio = 1.107 or 10.7% increase

similar to 615.834 on p. 82

T = .09	.8366	.9631	
T = .08	.7431	.8571	1.154
	.0935	.1060	~~1.2~~ 1.134

13.4% at halfway up

T = .08	.7431	.8571	
= .07	.6419	.7419	1.158
	.1012	.1152	1.14
= .06	.5342	.6187	1.16
.05	.4219	.4896	1.162
	.1123	.1291	1.151

15% at 1/3 way up

9/26/66

Now have four pages of typescript on "Effects of steady hyperpolarizing current upon EPSP slope"

Just got back 615.835 & 615.836 (sep. 83)
with synaptic input to all five cpts.

medium
Here τ/25

615.835

ε = 0.1 in all five compartments.

① control

⑯ with hyperpol.

peak

.9152×10^-2 at T = .20 — 1.049 at T = .195

halfup

.467 .06 — .545 .06

halfdown

.458 at T = .94 — .523 at T = .91

halfwidth ≈ .88 — halfwidth = .85

Peak ratio = 1.146 or 14.6% increase

			factor
T = .06	.4677	.5446	
.05	.3779	.4406	1.167
	.0898	.1040	1.16

slope halfway up is increased about 16%

Now setup 615.837
.838 } ~~[illegible]~~ change to 20%
and to faster τ/50 input

Also 615.839 same with ε = .1 in ①, 1.0 in ⑤ foot $\tau/50$

615.979 E in (10) for Z_m = .9 ~~.4 .3.6~~

peak of .359 at T = .357

50% up .152
10% up .086
.086

foot = .065

foot to peak = .292

halfdown 1.153
halfup .152

halfwidth 1.00

compare with earlier result for medium $\tau/25$ p.169 Book 8

where peak was at .41 & foot to peak was .32
halfwidth was 1.21 - .19 = 1.02

Values rather close to above

9/27/66 Put in three new problems – see p. 92

Also, spend some time going over data & possible figures.

Plus 615.979 for fast τ/50
with ε in (10)

$Z_m = .9$

9/29/66 got back output

~~20%~~

615.839 $\varepsilon = 0.1$ in (1) & 1.0 in (5) 20% hypergd
fast τ/50

got distinct double peak

compare peak amplitudes

	(1) $\times 10^{-2}$	(16)	factor
1st peak	.3714 at T=.08	.4426 ~~.4271 $\times 10^{-2}$~~ at T=.08	1.193 nearly 20%
2nd peak	.4230 at T=.70	.465 at T=.69	1.10 about 10%

615.838 grade E in five cpts see p. 91 very similar

here 20% hyperpol for $\tau/50$

(1) control (16) with hyperpol.

peak

.8285 × 10^{-2} at T = .36 .9302 T = .34

Peak ratio = 1.123 12.3% rel to 20%

12%

T = .05	.4296	.5066
.04	.3500	.4138
	.0796	.0928

slope ratio 1.167 16.7% rel to 20%

17%

For this one ↑ try doubling hyperpol to try to shift peak earlier & get smaller peak factor

9/29/66

615.837 $\varepsilon = .1$ in all five cpts — fast $\tau/50$

20% hyperpol.

compare with 615.835 on p.92 — very similar

(1) control — peak — (16) with hyperpol

.4911 at T = .12 — .5762 at T = .11

halfdown

.246 at T = .83 — .288 at T = .806

Peak ratio = 1.17₂ or 17.2% rel to 20%

Slopes	control	with hyperpol	factor
T = .04	.3166	.3759	1.188
.03	.2371	.2818	1.19
	.0795	.0941	1.185

18.5%

Plan next computations
Double hyperpol of .838 to try to get more peak shift.
Modify .839 back to $\tau/25$
and put .8 in (4)

~~of 805B on p.28~~
~~803B on p.26~~ ~~Could try~~ .1 in (2)
peak too late .2 in (4)

Now Eqn (5) differs from Eqn (2) only in the constant representing the driving potential.

In other words, if $\gamma = \frac{a-b}{a}$

and if ~~W~~ $U \equiv \gamma W$

Then $\gamma \dot{W} + \gamma(1+g)W = \gamma a g$

or $\dot{W} + (1+g)W = ag$

which is exactly like (2)

$\therefore \; U(t) = \gamma W(t)$ where $W(t) = V(t)$

Soln of Case I-C ↗ … ↑ of Case I-A

In other words, solution for $U(t) = V(t) - V_\infty$ for case I-C is exactly $\gamma = \frac{a-b}{a}$ times the solution of case I-A.

Note that for hyperbol, $b < 0$

9/29/66 Sketched

Wrote up for Appendix to Theoretical EPSP paper, a version for Zim to look over to explain why should get factor of increase, without change in shape, for hyperpol., when Σ in single cpt.

Here is this reduced version, for single lump first

$$\dot{V} + (1+g)V = ag + b \qquad (1)$$

where g is conductance transient
a is driving potential ($E_E - E_R$) but see p. 102
b is steady state $I_m R_m$

Case I-A $b = 0$, $g(t)$ given, want $V(t)$ satisfying

$$\dot{V} + (1+g)V = ag \qquad (2)$$

Case I-B steady state for $b = \text{const}$, $g = 0$

$$V_\infty = b \qquad (3)$$

Case I-C superimpose $g(t)$ upon steady state, I-B

Let $U = V - V_\infty = V - b \qquad (4)$

Subst. $V = U + b$ in eq. (1)

obtain $\dot{U} + (1+g)(U+b) = ag + b$

or $\dot{U} + (1+g)U = (a-b)g + 0 \qquad (5)$

go to p. 97

(continued from p. 100)

And, if only this compartment has a conductance change, this is the only forcing term in the system, when expressed in terms of V_i. Hence, as before

$$V_i = \gamma W_i(t)$$

where $\gamma = \frac{a - V_{i\infty}}{a}$

and $W_i(t)$ is solution of Case II-A.

Now, could perhaps make clearer to some readers by doing explicitly for a two compartment model. Then can have simple expressions for steady state solutions for b const in cpt. ①

$$V_{1\infty} + c(V_{1\infty} - V_{2\infty}) = b$$

$$V_{2\infty} + c(V_{2\infty} - V_{1\infty}) = 0$$

$$V_{1\infty} + V_{2\infty} = b$$

$$(V_{1\infty} - V_{2\infty})(1+2c) = b$$

$$2V_{1\infty} = b\left(1 + \frac{1}{1+2c}\right)$$

$$V_{1\infty} = b\left(\frac{1+c}{1+2c}\right), \quad V_{2\infty} = b\left(\frac{c}{1+2c}\right)$$

If $c = 1$ get $V_{1\infty} = \frac{2}{3}b$, $V_{2\infty} = \frac{1}{3}b$

If $c = 2$ get $\frac{3}{5}$ & $\frac{2}{5}$

For compartmental problem

$$\dot{V}_1 + V_1 + c(V_1 - V_2) = b$$

$$\dot{V}_2 + V_2 + c(2V_2 - V_1 - V_3) = 0$$

. . . .

$$\dot{V}_i + (1+g)V_i + c\sum_{j\neq i}(V_i - V_j) = ag$$

. . . .

Case II-A, $b = 0$, $g(t)$ in ith cpt. causes $\{V_1(t), V_2(t)$ solution $\cdots V_i(t) \cdots\}$

Case II-B, steady state for $g = 0$, b const in cpt ① get standard $V_{1\infty}, V_{2\infty}, \cdots V_{i\infty}, \cdots$

Case II-C superimpose $g(t)$ in ith cpt. upon steady state of Case II-B

Define, for each cpt. $U_i = V_i - V_{i\infty}$

In ith cpt. get

$$\dot{U}_i + (1+g)(U_i + V_{i\infty}) + c\sum_{j\neq i}\{(V_i - V_j) - (V_{i\infty} - V_{j\infty})\} = ag$$

But from case II-C, we have $+c\sum_{j\neq i}(V_{i\infty} - V_{j\infty}) = -V_{i\infty}$

$$\therefore \quad \dot{U}_i + (1+g)U_i + c\sum_{j\neq i}(V_i - V_j) = (a - V_{i\infty})\,g$$

which differs from Case II-A only in the effective driving potential i.e. $dV_1/dT + (1+\varepsilon_1+g_1)V_1 + a(V_1-V_2) = P_1 + (1+\varepsilon_1+g_1)V_{eq}$

Better still

see p. 105

$(1+f_1)V_1$

$$dV_1/dT + f_1 V_1 + a(V_1-V_2) = P_1 + f_1 V_{eq}$$

$$dV_2/dT + f_2 V_2 + a(V_2-V_1) = P_2 + f_2 V_{eq}$$

where $f_1(t) = 1 + \varepsilon_1 + g_1$

$f_2(t) = 1 + \varepsilon_2 + g_2$

$$a = \frac{\text{core conductance between compartments}}{\text{membrane conductance of compartment}}$$

P_1 = st. st. polarizing potential $= I_1/G_m$ $\neq V_{1\infty}$

= polarizing current × membrane ~~conductance~~ of compartment.

Then, for $P_2 = 0$, and $f_1 = f_2 = 1$

Steady State solns are $V_{1\infty} = \left(\frac{1+a}{1+2a}\right)P_1$

$$V_{2\infty} = \left(\frac{a}{1+2a}\right)P_1$$

from page 99

9/30/66

What previous pages show is precise proportionality for $g(t)$ in a single cpt.

However, with $g(t)$ in more than one cpt, one cannot just average the separate effects because the separate systems are not the same. Approx. it may work, simply because g may be small enough to cause very little non-linearity.

Also, differencing (like on p. 136 of Book 8) could be illustrated most simply for two cpts.

Now examine notation to use for such a presentation.

$$\tau\dot{V}_1 + (1+\varepsilon_1+j_1)V_1 + \frac{g_{12}}{g_1}(V_1-V_2) = F_1$$

where $F_1 = \varepsilon_1(E_\varepsilon - E_r) + j_1(E_j - E_r) + I_{a1}R_m$

$= (1+\varepsilon_1+j_1)V_{eq} + I_{a1}R_m$?

could replace $I_{a1}R_m$ by $-P_1$ polarizing pot.

for pos P meaning hyperpol.

Alternative is not as useful

$$\dot{V}_1 + \frac{1}{\tau}(1+\varepsilon_1+j_1)V_1 + \frac{g_{12}}{C_1}(V_1-V_2) = \frac{(1+\varepsilon_1+j_1)V_{eq}}{\tau} + \frac{I_{a1}}{C_1}$$

$$V_{eq} = \frac{\varepsilon(E_\varepsilon - E_r) + j(E_j - E_r)}{1+\varepsilon+j} = V^*$$ of N.Y. Acad. paper

~~If~~ depol +, then hyperpol −

$\dot{V}_1$ = rate of change of voltage, $C_1\dot{V}_1$ = ~~charging~~ capacitative current
$= G_r \tau \dot{V}_1$

$\tau\dot{V}_1$ is ~~[illegible]~~ the rate of change of V_m in ①,
multiplied by τ to ~~[illegible]~~
→ give dimensions of voltage

$f_1(V_1 - V_{eq})G_r$ = sum of three parallel currents flowing thru G_r, G_ϵ & G_j

$a(V_1 - V_2)G_r$ = current flowing from ① to ②

$P_1 G_r = I_{p_1}$ = polarizing current applied, inside ~~rel~~ to outside at ①, Positive current makes inside less neg. & is depolarizing. Neg current makes inside more neg & is hyperpolarizing.

$(1+f_1)V_{eq}$
$\quad h$

notice that $f_1 V_{eq_1} = \varepsilon(E_\epsilon - E_r) + j(E_j - E_r)$

So that $f_1 = 0$ implies $\varepsilon = 0 = j$
& $f_1 V_{eq_1} = 0$

see p. 105

∴ Consider replacing $f_1 = 1 + g_1$ where $g_1 = \varepsilon + j$
and replacing $f_1 V_{eq}$ with $g \cdot V_{new}$
where $V_{new} = \dfrac{\varepsilon(E_\epsilon - E_r) + j(E_j - E_r)}{\varepsilon + j}$

effective driving V
but see p. 105

which is $\left(\dfrac{1+\varepsilon+j}{\varepsilon+j}\right)V_{eq}$ ~~≠~~ This may be

∴ for proposed appendix, use

$$\tau \dot{V}_1 + (1+f_1) V_1 + a(V_1 - V_2) = f_1 K + P_1$$
$$\tau \dot{V}_2 + (1+f_2) V_2 + a(V_2 - V_1) = f_2 K$$

~~For steady state hyperpolarizing current~~ $V_1(t) = \phi(f_1, f_2, P_1)$

Case A, transient f_2 in ②, $P_1 = 0$, $f_1 = 0$

~~get $V_1 = \phi_1$~~ let $\phi_A(t)$ be solution $V_1(t)$ for this case

I.C. $V_1 = 0 = V_2$ at $t = 0$

system
$$\tau \dot{V}_1 + a(V_1 - V_2) = P_1$$
$$\tau \dot{V}_2 + (1+f_2) V_2 + a(V_2 - V_1) = f_2 K$$

Solution will be called

Case B, $P_1 \neq 0$, $f_1 = 0 = f_2$

steady state problem $V_1 + a(V_1 - V_2) = P_1$
$V_2 + a(V_2 - V_1) = 0$

Solution $V_{1\infty}$

~~one reason~~ why it might be better (for some purposes) to drop E_2 + replace with G_{E0} + G_{J0}

p.105

10/1/66 referring back to previous pages

notice that $V_{eq} = \dfrac{\varepsilon(E_\epsilon - E_r) + j(E_j - E_r)}{1 + \varepsilon + j}$

which is same as V^* of N.Y. Acad. Paper
represents the steady state for an isolated compartment with ε & j.

It is not the driving potential, or even the Equilib. potential in the sense of H & H.

Note that for $\varepsilon = 0 = j$, above $V_{eq} = 0$
for $\varepsilon = \infty$, j finite, get $E_\epsilon - E_r = V_{eq}$
for $j = \infty$, ε finite, get $E_j - E_r = V_{eq}$

However, the effective driving potential, by which you multiply $G_\epsilon + G_j$ to get the ~~synaptic current~~, is

neglecting change in V_m

$$\mathbf{K} = \frac{\varepsilon(E_\epsilon - E_r) + j(E_j - E_r)}{\varepsilon + j} = \frac{1+\varepsilon+j}{\varepsilon+j} V_{eq}$$

$= G_\epsilon(E_\epsilon - V_m) + G_j(E_j - V_m)$

The key notion is "synaptic current" forcing fcn $G_\epsilon(E_\epsilon - E_r) + G_j(E_j - E_r)$

& that effective driving potential is that effective potential by which you multiply synaptic conductance to obtain ~~synaptic current~~ forcing fcn.

* Important points to remember to bring out in papers now in preparation.

Was reminded of these today when talking with Phil Nelson & Manfred Klee.

(1) falling phase of EPSP is apparently not purely passive

(a) overshoot to hyperpol

(b) some evidence of late conductance above normal

This can be due to

(a) late K permeability

(b) disynaptic inhibition !

(2) Rate of EPSP rise can be very slow in spite of somatic locus, if there is much temporal dispersion as in case of Klee's polysynaptics. This accounts for his slow rise, yet great susceptibility to hyperpol enhancement

My paper needs a section on rate of rise

considering { location
{ input time course

(3) Effective synaptic driving potential need not be $E_E - E_R$, because there may be I as well as E present.

Klee's polysynaptic EPSP triples for 30 mV hyperpol:

$$\frac{30 + V_{eq}}{V_{eq}} = 3 \quad \text{or} \quad V_{eq} = 15 \text{ mV}$$

have to require $\frac{f_1 K_1 - f_1 V_{1\infty}}{f_1 K_1} = \frac{f_2 K_2 - f_2 V_{2\infty}}{f_2 K_2}$

or $1 - \frac{V_{1\infty}}{K_1} = 1 - \frac{V_{2\infty}}{K_2}$

or $\frac{V_{1\infty}}{K_1} = \frac{V_{2\infty}}{K_2}$

or $\frac{K_1}{K_2} = \frac{V_{1\infty}}{V_{2\infty}}$

But $\frac{V_{1\infty}}{V_{2\infty}} = \frac{1+a}{a} = 1 + \frac{1}{a}$; this $= 2$ for $a=1$

~~Suppose~~ In general K_1 & K_2 would not satisfy this, Even more so for ~~mult~~ ten compartment chain.

But, here, for fun, if $g_1 = 0$, $K_1 = E_c - E_r$

suppose $E_j - E_r = -.1(E_c - E_r)$

Then $K_2 = (E_c - E_r)\left(\frac{\varepsilon_2 - 0.1 g_2}{\varepsilon_2 + g_2}\right)$

~~Would need~~ $= (E_c - E_r)\left(1 - \frac{1.1 g_2}{\varepsilon_2 + g_2}\right)$

$\frac{K_2}{K_1} = \left(1 - \frac{1.1}{1 + \varepsilon_2/g_2}\right)$

whereas $\frac{V_{2\infty}}{V_{1\infty}} = \frac{a}{1+a} = \frac{a+1-1}{a+1} = 1 - \frac{1}{a+1}$

$\therefore a+1 = \frac{\varepsilon_2/g_2 + 1}{1.1}$ or $\varepsilon_2/g_2 = 1.1(a+1) - 1 = 1.1a + 0.1$

Let $x = \varepsilon_2/g_2$

$\frac{x - .1}{x+1} = \frac{a}{a+1}$

$ax + \frac{a}{10} + x - .1 = ax + a$

$x = 1.1a + .1$

10/3/66

For two compartments, demonstrate difficulty when G_ϵ in both compartments with hyperpol.

$$\tau \dot{V}_1 + (1+f_1)V_1 + a(V_1 - V_2) = f_1 K_1 + P_1$$
$$\tau \dot{V}_2 + (1+f_2)V_2 + a(V_2 - V_1) = f_2 K_2$$

where $K_1 = \{\varepsilon_1(E_\epsilon - E_r) + g_1(E_j - E_r)\}/(\varepsilon_1 + g_1)$
$=$ simply $E_\epsilon - E_r$, if $g_1 = 0$

$$K_2 = \{\varepsilon_2(E_\epsilon - E_r) + g_2(E_j - E_r)\}/(\varepsilon_2 + g_2)$$

Note that, if $\varepsilon_1(t)$ is not proportional to $g_1(t)$, then $K_1 \neq$ const.
$\varepsilon_2(t)$ — — — $g_2(t)$, $K_2 \neq$ const.

Also, in general, $K_1 \neq K_2$, unless $g_1 = 0 = g_2$

Now, for steady P_1, define $U_1 = V_1 - V_{1\infty}$, hence $V_1 = U_1 + V_{1\infty}$
$U_2 = V_2 - V_{2\infty}$, $V_2 = U_2 + V_{2\infty}$

Subst. in system of D.E. to obtain

$$\tau \dot{U}_1 + (1+f_1)(U_1 + V_{1\infty}) + a(U_1 - U_2) + a(V_{1\infty} - V_{2\infty}) = f_1 K_1 + P_1$$
$$\tau \dot{U}_2 + (1+f_2)(U_2 + V_{2\infty}) + a(U_2 - U_1) + a(V_{2\infty} - V_{1\infty}) = f_2 K_2$$

but from st. st. solution, have $V_{1\infty} = P - a(V_{1\infty} - V_{2\infty})$
$V_{2\infty} = -a(V_{2\infty} - V_{1\infty})$

$$\therefore \tau \dot{U}_1 + (1+f_1)U_1 + a(U_1 - U_2) = f_1(K_1 - V_{1\infty})$$
$$\tau \dot{U}_2 + (1+f_2)U_2 + a(U_2 - U_1) = f_2(K_2 - V_{2\infty})$$

If $U_1(t)$ solution of this is to be proportional to $\phi(t)$ solution for original problem with $P_1 = 0$, then would

(go to p. 107)

10/3 Zin agrees that my demonstration is valid for single conductance locus, provided that the initial condition is zero for the basic problem — which it is of course.

But it is worth noting that the whole gamut of superposition rules (input → output) are actually valid only if one assumes zero initial conditions in all cpts.

$$G_E(E_E - V_m) + G_j(E_j - V_m) = \text{synaptic current}$$

$$G_E(E_E - E_r) + G_j(E_j - E_r) = \text{forcing function}$$

If $j = 0$, $E_E - E_r$ is the initial driving force but $E_E - V_m$ is the time varying driving force

and $(E_E - E_r - V_{200})$ is the new initial driving force with steady state polarization.

10/4/66 Wrote 1st draft of appendix in the morning.
based on p. 108, but ~~emphasis~~ explicit about
synoptic current & forcing fcn as on p. 110

Saw Jose del Castillo's friend in afternoon
Dr. Antonio Bonnet Seoane
Div. of Biomedical Instrumentation
School of Medicine of Puerto Rico
San Juan, Puerto Rico 00905
Tel - 725 - 5712

He is concerned with establishing a research computer & with promulgating biophysics & computation, initially needs to be fairly elementary seminars. Would welcome seminars at any time.

~~Late~~ Afternoon talked with Phil, Bob, Tom

agreed to put points (X) & (Y) in earlier figure & to put data points in the multi cpt. fit figure.

Also Decided do want new figure for $Z_m = \begin{cases} .9 \\ 1.8 \\ 3.6 \end{cases}$

Now a few more computations.

10/5/66

Went over joint manuscript myself this morning

This afternoon, surveyed computations; aim to plan next ones.

[Hyperpol Series] see p.88 and here for assessment.

Page Ref	Prob No.	E values	E timecourse	foot to peak	halfwidth	Comment
p69	615.831	.1 in (1), .3 in (4)	τ/25	.14	.99	too early
73	.832	"	.3 in (3) & (4)	"	.33	1.17	fair
74 & 80	.833	" .4 in (4), .5 in (5)	"	~.64		
82	.834	" .3 in (3), .4 in (4)	"	.37	1.23	fair

For 17% hyperpol in (1), .834 gave 17% slope increase & 10.9% peak increase

Weighted mean ↑ see p.83

Page Ref	Prob No.	E values	E timecourse	foot to peak	halfwidth	Comment
p.92	.835	.1 in all five	τ/25	~.20	16%	14.6%
91	.836	.1, .2, .3, .4, .5	"	~.40	14%	10.7%

Change to 20% hyperpol and fast τ/50

Page Ref	Prob No.	E values	E timecourse	foot to peak	halfwidth	Comment
p.96	.837	.1 in all five	τ/50	.12	18.5%	17.2%
95	.838	.1, .2, .3, .4, .5	"	.36	17%	12%
94	.839	.1 in (1), 1.0 in (5)	"	.08		

(10/5/6) Change to 40% hyperpol and τ/25

Setup

615.840	.1 in (1), .6 in (4),	τ/25	40%
.841	.1 in all five	"	40%
.842	.1, .2, .3, .4, .5	"	"

	.980	$Z_m = 3.6$	($\lambda_{12} = 0.625$)	τ/50	E in (10)
	.981	"	"	"	(1)
need	.982	"	"	"	(7)

615.980 $Z_m = 3.6$

$\varepsilon = .1$ mi (10)

peak = $.3382 \times 10^{-4}$ at T = 1.76

50% up .969
10% up .598

4 | .371

.093

foot .505

foot to peak = 1.255

50% down = 3.171
half up .969

halfwidth 2.202

615.981 $Z_m = 3.6$

$\varepsilon = .1$ mi (1)

peak = $.3701 \times 10^{-2}$ at T = .078

50% up .0256
10% up .0086

.0170

foot = .0046

foot to peak = .073

50% down = .287
half up .026

halfwidth .26

10/7/66 ~~&~~ 10/19/66 got back computations

615.840 ε=.1 in ① } with + without 40% hyperpol.
ε=.6 in ④ }

control peak = .7256 $\times 10^{-2}$ at T = .46
hyperpol " = .9177 at T = .17 ← note, shifted to less than half.

factor of increase 1.266 26.6%

slope .04 to .05 is about 39% increased

615.841 control peak = .9152 $\times 10^{-2}$ at T = .20 } small shift
hyperpol 1.223 $\times 10^{-2}$ @ T = .19 }

ε=.1 in all five cpts.

factor = ~~1.22~~3 or ~~22.3%~~ 34%
1.34

615.842 with ε=.1 in ①, .2 in ②, .3 in ③, .4 in ④, .5 in ⑤
peak shifted from T = .405 to .37

peak amplitude $\frac{.2043}{.1637}$ = 1.25 or 25%

slope at .7	.6419	.8694
.6	.5342	.7259
	.1077	.1435

factor 1.335

615.982 $Z_m = 3.6$, Σ in (8)

peak = $.5482 \times 10^{-4}$ at 1.36

50% up .679
10% up .394
4 | .285
.071

foot — .323

foot to peak = 1.037

numerical error was corrected had 2.77 10/13/66

half down = 2.707
half up .679

halfwidth 2.03

615.983 $Z_m = 3.6$, Σ in (6)

peak = $.1366 \times 10^{-3}$ at .91

50% up .427
10% .233
.4 | .194
.0485

half down = 1.995
half up = .427

foot = .184

halfwidth = 1.57

foot to peak = .726

10/10/66

Setup 615.843 $\varepsilon = .1$ in (1) 20% hyperpol
$\varepsilon = .5$ in (4)

615.982 ε in 8 } $Z_m = 3.6$
.983 ε in 6 }

Compare p. 116

Got back 10/11/66

i.e. .5 in (4) was too little

615.843

control peak = $.6601 \times 10^{-2}$ at T = .17
hyperpol peak = $.7804 \times 10^{-2}$ at T = .165

factor of peak increase = 1.17_3 or 17.3% rel to 20%

Should try .55 to shift control peak out farther

~~or try .3 in (1) & (6)~~

better keep single to ~~simplify~~ ~~intended~~ figure

615.844 & 5

615.984 $\varepsilon = .1$ in (3) & (4) } to correspond to
$\varepsilon = .2$ in (9) & (10) } 615.824B p. 43 which is (C) of figure

615.985 $\varepsilon = .1$ in (5)

615.986 $\varepsilon = .1$ in (2)
615.987 $\varepsilon = .1$ in (3)

all for $Z_m = 3.6$

615.986 $Z_m = 3.6$ ε in ②

peak = $.1408 \times 10^{-2}$ at T = .19

50% up .068
10% up .028
.040

half down .676
half up .068
halfwidth .608

foot = .018

foot to peak = $.17_2$

615.987 $Z_m = 3.6$ ε in ③

peak = $.7011 \times 10^{-3}$ at T = .355

50% up ~~at~~ .135
10% up ~~at~~ .062
4 | .073
.018

half down 1.038
half up .135
halfwidth $.90_3$

foot = .044

foot to peak = .311

10/12/66 Got back six runs put in yesterday

615.984 $Z_m = 3.6$ $\varepsilon = .1$ in (3) & (4), $\varepsilon = .2$ in (9) + (10) foot $\varepsilon/50$

peak = $.1064 \times 10^{-2}$ at T = .42

50% up at	.157	half down	1.44
10%	.070	half up	.16
	4 | .087		
	.022		
foot = .048		halfwidth	1.28

foot to peak = .37

(try for earlier)

615.985 $Z_m = 3.6$ ε in (5)

peak = $.2268 \times 10^{-3}$ at T = .72

50% up at	.319	half down	1.68
10% up	.166	half up	.32
	4 | .153		
	.038		
foot = .128		halfwidth	1.36

foot to peak = $.59_2$

chan of 5 x 0.4 = 2.
$Z_m = 4 \times .4 = 1.6$

615.845 ~~Z_m 3.6~~ 20% hyperpol
ε = .1 in (1), ε = .3 in (4) & (5)
got dip in middle

~~medium time course~~
chan of 5

~~Z_m 3.6~~

Setup 615.846 20% hyperpol with ε = .1 in (1) alone
615.847 " .55 in (4) alone
48 " ε = .1 in (2), .6 in (4)
615.988 $Z_m = 3.6$ ε = .1 in (2) + (3), ε = .2 in (9) & (10)
.989 " (1) & (2) "
.990 " ε in (7) alone

10/12/66

chain of 5 ×0.4 = 2.2

$Z_{in} = 4 \times 1.4 = 1.6$

615.844 ~~Z_{in} 3.6~~ 20% hyperpol

$\Sigma = .1$ in (1), $\Sigma = .55$ in (4)

Shape pretty good, compare 840, p.116
843, p.118

control	hyperpol
peak = $.6888 \times 10^{-2}$ at $T = .43$	$.7884 \times 10^{-2}$ at $T = .17$

∴ peak time shifted by factor greater than 2
peak increased by factor = 1.145 14.5% out of 20%

~~Slope~~

~~Slope Characteristics~~

Slope at $T = .04$ to $.05$

control	hyperpol	factor
.003384	.004036	1.194
.002587	.003084	1.194
.000797	.000952	1.195

∴ slope increased 19.5% halfway up

615.989 $Z_m = 3.6$, foot ~ $\tau/50$ ① & ② ε = .1
⑨ & ⑩ ε = .2

peak = $.464 \times 10^{-2}$ at T = .10

50% = .03
10% ≈ .01
foot ≈ .005

halfdown .435
topig .03
halfwidth .405

foot to peak = .095

~~Try 615.991 with~~

Because 988 & 989 were too early, with too little halfwidth

615.991
Should try ε = .3 in ③ with .2 in ⑨&⑩

also 615.992 Z_m = .9, ε in ②
.994 " , ε in ④

and 615.849 ε = .1 in ①, ε = .5 in ③

10/13/66 Got back computer output

Sep. 117

615.990 $Z_m = 3.6$, foot $\tau/50$ ⑦ alone

peak = $.8444 \times 10^{-4}$ at $T = 1.12$

50% up = .545
10% up = .308
4|.237
.059

halfdown = 2.34
halfup .545
halfwidth 1.8

foot = .25

foot to peak = 0.87

615.988 $Z_m = 3.6$, foot $\tau/50$ ε = .1 in ② & ③
.2 in ⑨ & ⑩

peak = $.2005 \times 10^{-2}$ at $T = .25$

50% up = .085
10% .032
4|.053
.013

halfdown = .89
.085
halfwidth .805

foot = .02

foot to peak = .23

615.848 20% hyperpol

$\xi = .1$ in (2)

$\xi = .6$ in (4)

peak too late, at T = .50

& did not shift

factor was $\frac{.3787}{.3444} = 1.1$

which is average of (2) & (4) hyperpol factors

Slope 615.846	Control	with hyperpol	factor
T = .05	.003373	.004025	
T = .04	.002583	.003080	
	.000790	.00094521	1.197
			i.e. 19.7%

Slope 615.847			
T = .28	.002419	.002595	1.073
.27	.002276	.002440	1.072
	.000143	.000155	1.084
			approx 8%

10/13/66 – 10/14/66

615.846 20% hyperpol control with E in (1) alone

Control for 615.844 on p. 122

	without hyperpol	with hyperpol
peak	$.6091 \times 10^{-2}$ at T=.13	$.7281 \times 10^{-2}$ at T=.13

factor 1.196

at T=.43, value is .2875
.4014
.6889
agrees cf. p. 122

at T=.17 value is .69965
.08628
.78593
? a little short imperfect

for slopes see left

615.847 20% hyperpol control with E in .55 (4) alone

	without hyperpol	with hyperpol
peak	$.4684 \times 10^{-2}$ at T=.66	$.5078 \times 10^{-2}$ at T=.66

at T=.43

factor 1.084

at T=.17

cf. 7.7% hyperpol in (4) ?

approx 8%

Note that not perfect 7.7% increase everywhere in .847 presumably because I.C. were not perfect st. st. values as suggested by ~~error at very be~~ discrepancy at earliest times i.e. control is bigger than hyperpol for T=.07 to .13 ? machine error?

Equalizing Time Consts.

Phil called back 10/18/66

He analysed several more examples.

He got an average $\tau_0/\tau_1 \doteq 3.7$ for several cells.

Difficulty with semilog plot occurs apparently only for those cells with large anomolous rectification.

It would be nice if we could justify regarding these as a different cell type, with more accomodation.

Phil inclined to prepare a short joint note for Exp. Neurol.

10/14/66

Yesterday, Phil got interested in checking my equalizing time constant semi-log peel plot against his current step response data. Today, we looked at some of these results. They were encouraging. Two plots of $\frac{V-V_\infty}{V_0-V_\infty}$ on semilog paper worked fairly well. Then we tried semilog plotting of slope, $\frac{dv}{dt}$. We found only beginning of tail, but, using the τ_0 obtained from $V + \frac{dv}{dt}$ plot, the tail could be drawn with fair confidence, and peeling gave a reasonable result.

Cat 1568	$\tau_0 = 8$ msec $\tau_1 = 3.5$ msec	Ratio 2.3
Cat 1593	$\tau_0 = 6.25$ $\tau_1 \cong 2$	Ratio 3.1

These agree with Z_m between 2 & 3, as worked out in my theory of equalizing time constants. The slope data ran from .5 to 10 msec. The last four points, in each case, agreed quite well with the tail slope taken from the $V + \frac{dv}{dt}$ fit

615.992 $Z_m = .9$, $\mathcal{E}$ in (2)

peak = $.1109 \times 10^{-2}$ at T = .072

halfup at .0268
10% .0108
4 | .016
.004

halfdown .2446
halfup .0268
halfwidth .2178

foot = .0068

foot to peak = .065

615.994 $Z_m = .9$, $\mathcal{E}$ in (4)

peak = $.6398 \times 10^{-3}$ at T = .12

halfup .049
10% .024
4 | .025
.006

halfdown .575
halfup .049
halfwidth .526

foot = .018

foot to peak .102

10/17/66

Got back some output

615.849 20% hyperpol. $\varepsilon = .1$ in (1)
$\varepsilon = .5$ in (3)

control peak = $.10326 \times 10^{-1}$ at T = .30 } little shift
hyperpol " = $.1177 \times 10^{-1}$ at T = .29 }

need to reduce amount in (3) in order to get shift to T = .17

factor here is 1.14 or (14%)

try reducing input in (3)

Could increase both by factor of 10. + set scale to .09

615.991 $\varepsilon = .3$ in (3) with $\varepsilon = .2$ in (9) & (10) $Z_m = 3.6$

This is search for good point for figure.

peak = $.2097 \times 10^{-2}$ at T = .36

50% up = .135
10% up .062
.073
.018

halfdown 1.127
halfup .135
halfwidth .992

foot = .044

foot to peak = .316

note this peak ampl nearly doubles that of .984. (p. 120)
& that is why halfdown comes earlier.

Could try .2 in (3)

Normally, EPSP involves a flow of synaptic current from presynaptic side, across R_c, into postsynaptic interior & then out across R_N

As shown at lower right, when the impulse blocks upstream from the point where st. st. axonal V_m is equal to the equilib. Pot. E_ϵ (which Tom, Bob, and Phil all feel sure to be the case), then the axonal $\frac{dV_i}{dx}$ is decreased at the contact region. This means a reduction of (post to pre) current from the st. st. amount; rel. to the steady state, this appears as a pos. pre to post current, giving an EPSP in the normal direction.

If, as now seems unlikely, the impulse were able to invade past the point were $V_m = E_\epsilon$, then, as shown in red, the axonal $\frac{dV_i}{dx}$ is increased at the contact region. This means an increase of (post to pre) current from the st. st. amount; rel to the steady state, this appears as a neg. pre to post current, giving an EPSP in the reversed from normal direction.

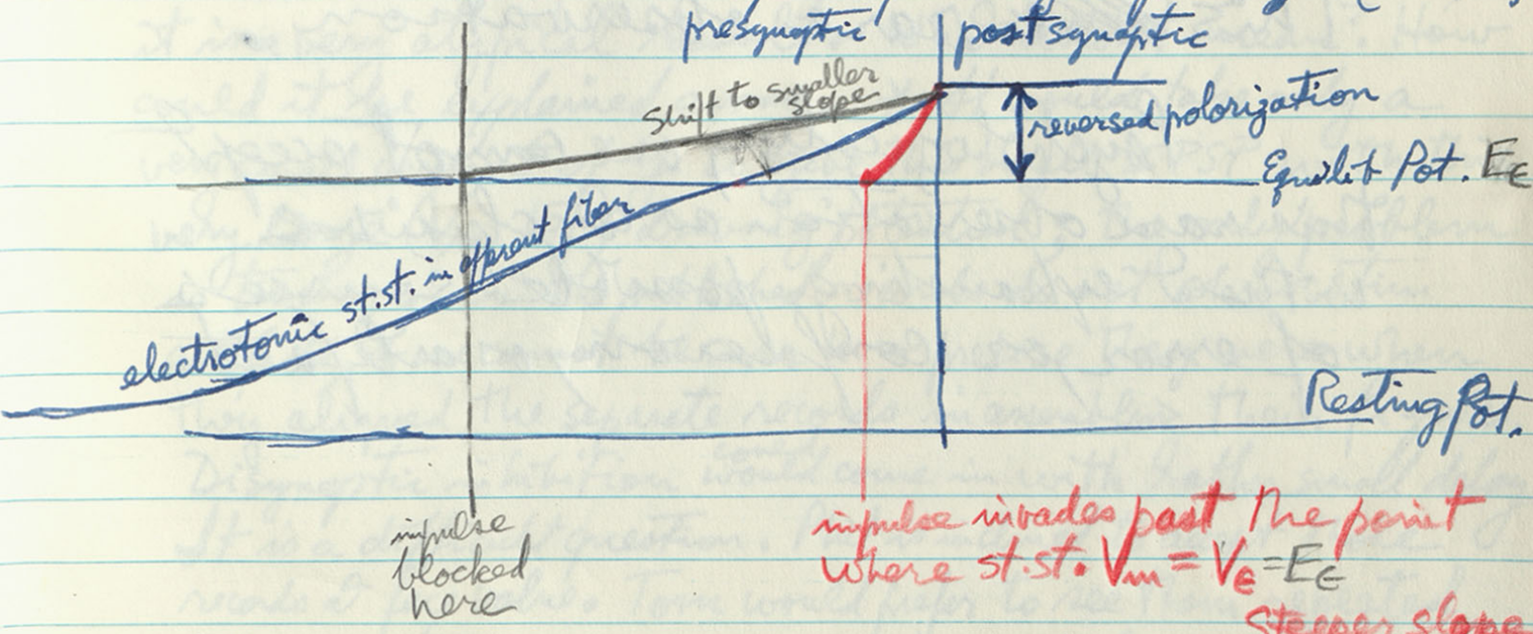
Therefore, the question really hangs upon the unknown properties of the spike generator in the presynaptic terminal membrane. How far-fetched would it be to postulate that impulse could invade to the red curve?

11/4/66

Past two weeks spent in writing & revising, both on Joint manuscript #V and my manuscript #IV, as well as discussing overall revisions with Tom Smith as well as Bob & Phil. Also, was out with cold for two days & below par for several more.

Also, partial differential equations course

Wed or Thurs. ~~Yesterday~~, discussed with others the tricky question of whether a low resistance electric coupled synapse could have its EPSP reversed by extreme steady state depolarization. I had thought it would, but Tom had convinced them it would not. In the end, we decided that Tom is probably right, but the crucial point is whether the afferent impulse will be blocked far upstream from the synaptic terminals (get no reversal) or if it could invade to the terminals inspite of being depolarized (get reversal).



Smaller slope means reduced post to pre current

Steeper slope increased post to pre

We also mused on the irony that few others could appreciate. Namely that Tom originally had thought to disprove the chemical model together with the Eccles "soma" model, but the introduction of dendritic location has saved the chemical model from that fate, and now, the only evidence that seems to separate the Chemical Model from our Low R electrical model is this ~~one~~ rare observation.

Psychologically, one cannot accept this rare observation as conclusive without exhausting possible sources of error, or confusion, or artefact.

11/4/66

There is one other important aspect of electric coupling neglected on previous page. That is the diphasic capacitative coupling that would be in addition to this more "D.C." aspect. The diphasic aspect may be normally masked, but when the "D.C." portion becomes very small, the diphasic aspect may become more prominent. First of all, what should be the polarity of the diphasic aspect? I do have the earlier computations on this that led to several puzzling results (? previous book).

We also discussed at length, whether Eccles, Coombs & Fatt's 1955 report of two only observations of reversal could be regarded as conclusive evidence in favor of chemical model. Tom did not feel so because of the rarity of the observation; he saw it only once? or twice? in spite of intensive search. In otherwords, it is a very atypical result. What does it mean? How could it be explained away. * It would take only a very small amount of g to give this small IPSP with this very large ($V_m - E_i$) driving potential; the only problem is timing. But the published records do not show stim artefacts, & we cannot be sure how precise they were when they aligned the separate records in assembling their figures. Disynaptic inhibition could come in with rather small delay. It is a difficult question. Phil is inclined to accept those records at face value. Tom would prefer to see them repeated before accepting them as the most crucial evidence.

The answer is: Single locations on branchlets do not solve ~~E~~PSP shape problem,

but combinations (wait for) work.

11/15/66

Also worked on the effect of different core resistance upon current flowing in cylinder placed in constant field.

see p. 138

11/15/66

Spent much time of previous week on revising drafts of joint paper.

Also, today, checked back on 665.013 & .014 Book 8
Branchlet GE see pp. 179 + 184

← also refer back to pp. 172 & 180

To make sure that branchlet does not give the shapes having long halfwidths with short time to peak.

for .013 in (13) estimate peak T ≈ .42

halfup	≈ .19	halfdown	≈ 1.35 extrap.
10%	.09	halfup	.19
foot	≈ .065	halfwidth	1.16
foot to peak	≈ .36		or 5.8 msec extrap.
	or 1.8 msec		

This appears to be no improvement

The reason (13) is better than (9) is because it is nearer to soma.

Note that (9) of .013 gives peak in (1) at T = .60 } same
& that (4) of .014 " " " " " } electrotonic distance

whereas (14) & (5) both give later peak times at (1)

foot to peak ≈ .50 or 2.5 msec, which is too much to fit data.

Now 665.103 examined on p. 26 of Book 9 (this book) cf p. 23
and this did give a good pair of shape indices
but this is already a combination of locations,
and therefore not essentially different from
other combinations. This is why it was
not pursued when first noticed 7/6/66. The positive
point is that combinations work without necessity of straight chain.
i.e. This is not an artefact of st. chain!

Now $\frac{dV}{dx} = \frac{\lambda C}{\cosh(h/\lambda)} \frac{d}{dx} \sinh\left(\frac{h}{\lambda} - \frac{x}{\lambda}\right)$

$= \frac{-C}{\cosh(h/\lambda)} \cosh\left(\frac{h}{\lambda} - \frac{x}{\lambda}\right)$

$\frac{dV_i}{dx} = C + \frac{dV}{dx}$

at $x=0$ and $x=2h$, $\frac{dV}{dx} = -C$

at midpoint, $x=h$, get $\boxed{\frac{dV}{dx_{mid}} = \frac{-C}{\cosh(h/\lambda)}}$

$\cosh z = 1 + \frac{x^2}{2!} + \frac{x^4}{4!} + \dots$

$\therefore \frac{dV_i}{dx_{mid}} = C\left[1 - \operatorname{sech}\left(\frac{h}{\lambda}\right)\right]$

for h/λ very small

$\left[1 - \operatorname{sech}\left(\frac{h}{\lambda}\right)\right] \simeq \frac{1}{2}\left(h/\lambda\right)^2$

and $\frac{dV_i}{dx_{mid}} \simeq \frac{C}{2}\left(\frac{h}{\lambda}\right)^2$

$-g_i \frac{dV_i}{dx} = -\frac{Ch^2}{2r_m}$

which is the maximum current that can flow across the membrane

$\int_0^h \frac{Cx\,dx}{r_m} = \frac{Ch^2}{2r_m} = \frac{C\left(\frac{h}{\lambda}\right)^2}{2r_i}$

for an isopotential core

for h/λ very large

$\operatorname{sech}(h/\lambda)$ becomes very small

and $\frac{dV_i}{dx_{mid}} \simeq C$

$-g_i \frac{dV_i}{dx} = -Cg_i = -\frac{C\lambda^2}{r_m}$

which is the applied gradient times the core conductance

$g_i = \frac{1}{r_i} = \frac{\lambda^2}{r_m}$

Ratio of $\frac{\text{core current}}{\text{~~max~~ for isopot. core}} = 2\left(\frac{\lambda}{h}\right)^2\left[1 - \operatorname{sech}\left(\frac{h}{\lambda}\right)\right]$

range for dendritic trees { for $h/\lambda = \frac{1}{2}$, get $2(4)(1-.886) = 0.91$

1 — $2(1)(1-.65) = 0.70$

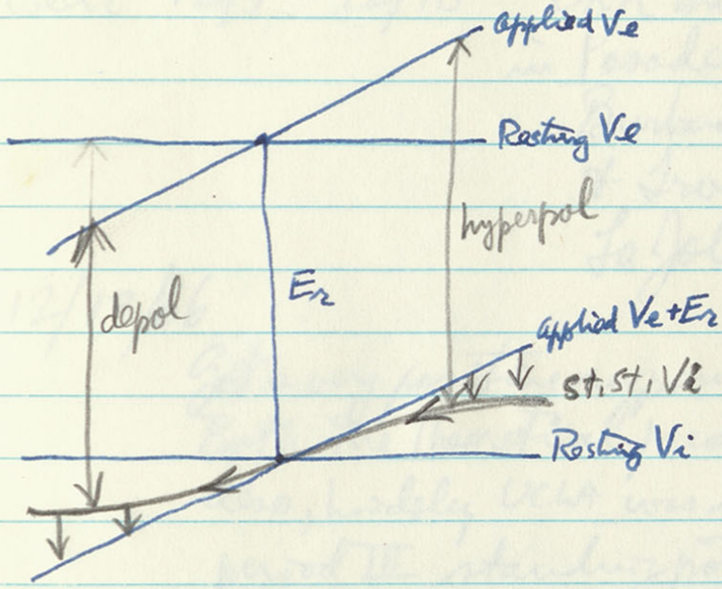
2 — $2(\frac{1}{4})(1-.266) = 0.37$

} $\frac{1}{2}$ is a representative value

4 — $2(\frac{1}{16})(1-.037) = .12$

11/16/66 (p. 121 et seq of Book 6)

Referring back to earlier results, place cylinder, length 2h in a constant $\frac{dV_e}{dx} = C$



St. St. solution

$$V = V_i - (V_e + E_r)$$

$$= \lambda C \left\{ \frac{\sinh(h/\lambda - x/\lambda)}{\cosh(h/\lambda)} \right\}$$

and at $x = 0$

$$V_{(0)} = \lambda C \tanh(h/\lambda)$$

$< \lambda C$ for this case

for $h/\lambda < 0.25$, get $V_0 \simeq hC$ within 2%

for $h/\lambda > 2.3$, get $V_0 \simeq \lambda C$ within 2%

$< hC$ for this case

For cylinder 2 mm long, h = 1 mm

Let C = 10 mV/mm

Then for λ	h/λ	V_0
250 μ	4	$\lambda C = 2.5$ mV
1 mm	1	7.6 mV
1 meter (iron wire)	10^{-3}	$hC = 10$ mV

for λ very large, h/λ very small, V_i remains essentially isopotential; drop all across membrane

for λ very small, h/λ very large, $\frac{dV_i}{dx} \simeq C$ at middle & current is limited by core resistance

---

Useful to look at mid-core-current $= -g_i \frac{dV_i}{dx}_{mid}$

$$g_i = \frac{1}{r_i} = \frac{\lambda^2}{r_m}$$

week 11/28 – 12/3 { did some work on theoretical EPSP paper
also prepared for trip to Pasadena & La Jolla

week 12/5 – 12/10 ONR Interdisciplinary Sciences Symposium
in Pasadena Dec 5 & 6
Burbank (Lewis) } Dec. 7
& Irvine Campus }
La Jolla Dec 8, 9, 10

12/13/66

Got a very positive response to dendro-dendritic story. Both the theoretical prediction & implications of pathway. Also, Lindsley UCLA was impressed by explanation of the period III standing potential which may apply to numerous other situations. Livingston was impressed by interdisciplinary aspect of d-d paper. Hagiwara, Bullock, Livingston all pleased to have me visit next summer.

Best papers at Pasadena were Morrell, Deutsch, Rosenzweig & mine

Film of peripheral nerve growth was interesting

Gerard & Scheibel's did not come

Stewart did not go across very well; he still seems to want both hardware & biological claims without any compromise. Very defensive to any comment.

Now, must get back to completion of final draft of theoretical EPSP paper.

January 5 & 6, ~~1966~~ 1967

Eureka, finished "Theoretical Synaptic Potential" paper. Have ten xerox copies ready with figs etc. Plan to have conference with all four collaborators aboard the set of five papers on Monday Jan 9.

Put early drafts, memos, plots, charts, tables in ~~filling~~ cabinet, Col 1, row 2.

Jan 9, 1967 had meeting with all collaborators Produced improved summaries & abstracts

Jan 11, 1967 Clearances came thru for papers IV & V in Arthritis.

Jan 10, 11, 12 Cataract operation: Udo at Sibley Hospital

Jan 13, 1967 Completed modifications & retyping based on suggestions of others re pages 16, 35 and 40 of Theoretical Paper

Also, today Zim asked me to prepare a new, updated form 57 for processing.

1/16/67 Theoretical EPSP Paper

Made up original & one xerox copy for submission for publication.

is changed in pencil

In existence 10 xerox copies before ref. nos. changed
3 xerox copies made today
1 original with modifications
14

But some lack figs, fig legends, tables & references

Of original ten, 1 needed for clearance
4 for collaborators
1 for Mike Fuortes
6 leaving four copies which I have used for xerox figs, legends etc.

After original ten xeroxed, revised pp. 16, 35, 40
& Dorothy also retyped 3, 5, 6, 9, 41
& corrected Table I
as well as ref. nos.

Sending off original & one of the three new xeroxes.

This leaves Two complete xerox copies in final form
and four incomplete " " of the earlier form

Submitted in person by Tom Smith 1/17/67
to Physiol. Soc!

1/25/67

New form 57 & supporting curriculum vitae etc completed.
Now must clear away backlog of chores.

✓ 1/30/67 1. Abstract for ONR Pasadena
✓ " next week 2. Arrangement to resume work with Gordon Shepley
✓ 1/31/67 3. Reply to Francis Schmitt invitation
✓ 2/15/67 to Berkley request for opinion
✓ 1/31/67 to Louise Marshall
to Livingston
to Harmon
? del Castillo
✓ 2/15/67 Hellerstein

2/1/67

Rescaling neurons

Worked out a memo for Phil & Bob Burke today. Here is summary of most interesting points, most of which I have worked out before.

For N equal dendritic trees, cylindrical surface area $A_D = NL\pi d$

For a spherical soma $A_S = 4\pi a^2$

Dendritic to soma surface area ratio, $A_D/A_S = (NLd)/(4a^2)$

To preserve A_D/A_S, one possibility is N constant, $L \propto d \propto a$

another " " ", $L^{3/2} \propto d^{3/4} \propto a$

But of course, N could change also.

$$G_D = N G_\infty \tanh(L/\lambda)$$

$$G_\infty = \frac{1}{\lambda r_i} = \frac{\lambda}{r_m} = \frac{\lambda \pi d}{R_m} = \frac{L\pi d}{R_m}\left(\frac{\lambda}{L}\right)$$

$$\therefore N G_\infty = \left(\frac{A_D}{R_m}\right)\left(\frac{\lambda}{L}\right)$$

and →

$$\boxed{G_D = \left(\frac{A_D}{R_m}\right)\left(\frac{\lambda}{L}\right)\tanh(L/\lambda)}$$

Also, $G_S = A_S/R_m$

(for R_m constant)

$$\therefore \rho = G_D/G_S = (A_D/A_S)(\lambda/L)\tanh(L/\lambda)$$

$$R_N = \frac{R_m}{A_S + A_D(\lambda/L)\tanh(L/\lambda)} = \frac{R_m}{A_S(1+\rho)}$$

A little more generally, $\rho = \left(\frac{N \not{L} \pi d}{A_S}\right)\left(\frac{\lambda}{\not{L}}\right)\tanh(L/\lambda)$

Still more generally $\rho = \frac{\pi}{A_S}\sum_j \not{L_j} d_j \left(\frac{\lambda_j}{\not{L_j}}\right)\tanh(L_j/\lambda_j)$

There are many other rescaling cases possible.

(A) Suppose N changes with neuron size -

(B) Suppose R_m changes with neuron size

(C) Suppose A_D/A_S " " " "

(D) suppose The relations L vs a

d vs a

are different from the cases considered.

Case III, suppose $\tanh(L/\lambda) \approx 1$

$$\rho \simeq \left(\frac{A_D}{A_S}\right)\left(\frac{\lambda}{L}\right) \quad \text{constant}$$

Then increase of $\frac{A_D}{A_S}$ has to be compensated by increase of $\frac{L}{\lambda}$

i.e. more remote dendrites.

Conversely, decrease of $\frac{A_D}{A_S}$ compensated by decrease of $\frac{L}{\lambda}$

2/1/67 If we constrain $\left\{ \begin{array}{l} R_m \\ N \end{array} \right.$ constant, we can use the simple form

$$\rho = \left(\frac{A_D}{A_S}\right)(\lambda/L)\tanh(L/\lambda)$$

Case I; set ρ constant, (A_D/A_S) constant, N constant, R_m const

~~first two~~ Together, these imply that also L/λ constant

i.e. $Ld \propto a^2$ and $L/\sqrt{d} = \text{const.}$

$\therefore L \propto d^{1/2}$

$Ld \propto L^3 \propto a^2 \propto d^{3/2}$

i.e. $L \propto a^{2/3} \propto A_S^{1/3}$ $\quad\therefore a \propto d^{3/4} \propto L^{3/2}$

$d \propto a^{4/3} \propto A_S^{2/3}$ $\quad$ or $L \propto a^{2/3}$ and $d \propto a^{4/3}$

$Ld \propto a^{2/3+4/3} = a^{6/3} = a^2$

For such scaling $R_N \propto \frac{1}{A_S}$

Case II, suppose $L \propto d \propto a$, preserving A_D/A_S, but not ρ

Here also N and R_m are const.

Here $L/\lambda \propto a/\sqrt{a} \propto \sqrt{a}$

Suppose we double a, thus quadrupling area & increasing $\sqrt{a}$ by 1.414 (but preserving A_D/A_S of course)

If in state 1, $L/\lambda = 1.0$

Then $\frac{\rho_2}{\rho_1} = \frac{(1.414)^{-1}}{1} \frac{\tanh(1.414)}{\tanh(1)} = (0.707)\left(\frac{.889}{.762}\right)$

$= \frac{.628}{.762} = 0.824$ $\quad$ i.e. ρ decreases with increase in size because L/λ is increasing

$$\frac{R_{N_2}}{R_{N_1}} = \frac{1(1+\rho_1)}{4(1+0.824\rho_1)}$$

if $\rho_1 = 5$, get $\frac{6}{4(1+4.12)} = \frac{6}{20.5} = \frac{1}{3.4}$ $\quad$ i.e. four fold increase in area causes less than fourfold decrease in R_N.

Gordon thinks we should try to find name for these new synaptic pathways.

Also, he thinks it would be good to simulate the mitral granule interactions; ① to prove to doubters (this does not intrigue me)

but also of course ② New things would probably turn up,

He thinks of oscillating waves generated by granule population as part of oscillatory interaction. My rough computation showed that granule re/ri ≃ 25

It is interesting that my computer computation used 10 for granule compared with values less than 1 for mitral.

I urged him to explore marsupials and insectivores or (molea star nose) with the hope that he might find significantly different arrangements or numbers of the mitral + granule populations & O. Nerve.

With anteater, it ought to be easy to narcotize the cut olfactory nerve without doing so to bulb. Then one could study da offere

2/13/67

Gordon Shepherd was here last week. We worked on the problem of figures and text for completion of Olfactory Bulb paper. I will summarize & recap results of this week on next page. see pp 157–

Today, received reminder to convert all programs from Honeywell 800 to 360 before end of March. Therefore decided to start ball rolling. Contacted

Jim Standish 65265
Room 1104 Bldg 12

who is Open Shop Programmer liason.

Also, got BOX 187 assigned in Production Room.

Put in WXR611C } Branch extrapolation
WXR69C
WXR82C } plotting subroutine

To be converted by Zander's program VEZ499
and charged to conversion account 04504-15925

ferented bulb.

2/14/67

Don Walter phoned.
He & Mary Brazier are organizing a workshop.
Feature Tukey [End of March]
Also other statisticians & physiologists
Wondered if I would explore with them
the relation of my field calcs. to their
statistical analyses.
I said no, I have to finish writing paper
with collaborator.

Also, earlier, heard Fomin give a very modest
seminar about developing Mathematical
Biophysical studies at Inst. of Biophysics, Moscow.
This is where group pursued my branching studies
into syncitial input resistances.
Fomin's model of excit. & refract. seemed to
be terribly simple, but he may have a
better model which he was not discussing.

2/15/67 I think it would be a good idea
for me to get back to my excitation
model and perhaps encourage John Evans
to pursue some the mathematical
stability problems.

But first, perhaps cleanup spherical soma
field paper. Spend some time today looking
these over, after getting letters off and
before resuming Olfactory Bulb next week.
Need some sort of break.

see p. 146

2/21/67 Plan to convert more HAC programs.

Refer back to page 88 of Book 5

And pages 42, 61 & 62 of Book 5

Initial calcs were with WXR 795C main 796
93C } R.K 96
94C } 97
But had made an 95C extracall
unsuccessful change 82C plot
(problem with arguments & equivalence)
to 796C with 96 & 97

Today, corrected blunders & renumbered 797
with 98
& 99
in preparation for 95
conversion by Zauber program 82
VEZ499

see p. 152
this book

Also WXR 751C ⟶ WXR 752C
for membrane model should be converted.

Also, earlier field & current step programs.

Sept 65, I went to Tokyo
Nov 65, Gordon pieced together "fourth draft" and had this typed in Sweden.

Although Gordon returned from Sweden Nov. 66 I was tied up with completing EPSP papers which were not finished until Jan 67.

Feb. 6-10 Gordon spent week here to reactivate project.
We aim to finish during March 67.
He has taken on several figure revisions,
I am to work on Part III (transition to old Fig. 5)
& he is working on Discussion which we made many notes on.
Finally we will rewrite introduction.

see pp. 151, 152

Monday 2/27/67

About ~~to~~ complete O'Bulb Paper

Brief Chronology

Gordon Shepherd arrived September 1962

I Developed program during 1963 (Book 3)

WXR 791C got working in January 1964

see pp 67–74 of Book 3

pp 77–82 " "

Added giant axial ~~extracell~~ & V^4 (steeper onset) April 64

WXR 793 C p. 15 Book 4

Active Membrane separate WXR 751C p. 44 " "

Granule & ~~leswood~~ ~~III~~ Aug & Sept 64 p. 56–67 "

72–77

| Sept-Oct 1964 | ~~developed~~ incomplete first draft

See notes ~~pp~~ 78 (GEC) — 86 (cone diagrams

pp. 89 shunt current, conical re } Book 4

pp 91–94

and first 56 pages of Book 5

~~details re figures~~

Windup notes pp. 49–56 of Book 5 also p. 42

November 64, I corrected errors & developed text on punctured sphere & cones

Second draft put on ditto

Jan 65, Gordon added a few changes & called this 3rd draft

July 65, after completing 4 author paper, Gordon & I roughed out figure legends & text (rough) to go with (Figs 5 thru 11).

Aug 65, Dorothy rough typed most of this material.

HAC Conversion.

WXR 611C ✓1
69C ✓1

WXR 797C ✓2
82C ✓1
95C
97C ✓2
98C ✓2 possible

WXR 546C ✓3
54C ✓3
55C ✓3
56C ✓3

WXR 752C ✓3

WXR 101C
10C
11C
12C

WXR 503C
51C
52C
33C

3/1/67

Yesterday, Did some work on Part III
Put together complete revision of Part II yesterday and this morning and gone to Dorothy to type.
Swam at Y at noon. Will see if such a routine can help get through writing chores. Also avoiding candy & coke snacks during writing, using tangerines and unsweetened tea; this way should avoid the weight gain likely to otherwise occur when in final throws of finishing a paper.

Now, must really come to grips with Part III

3/17/67 past two weeks, got some writing done
wrote La Jolla letters.
did HAC conversion 797C & 97C (plan more)
Investigated Kobe-Osaka, phoned State Dept.
Books from public library, borrowed OIR Tokyo Post Rept.
Today talked with Heinz Specht
Also have had trouble with sinus and ? earache

Still need HAC conversion of (see left).

Also, get new cards interpreted on 029 Interpreter Card Punch

His data from frog node are highly reproducible.

tetrodotoxin block sodium current completely
& leaves potassium " " intact.

In contrast tetraethylammonium blocks selectively
only the potassium conductance
and this can be graded & is reversible.

Both have no significant effect on leak current.
Most of the graphs presented had the leak current
subtracted out & thus presented only
Na & K current, either separately or together.

Effect of Ca^{++} is to shift τ_h and τ_m vs voltage
relations.
& thus to shift threshold.
→ effect on Na conductance
not on K conductance

3/29/67 John

Yesterday heard talk by Nicholls on glia (leech & necturus)

Glia have prominent resting potential that behaves according to Ke/Ki over large range

They do not have Na conductance change, or action pot.

Nerve activity causes slow depolarization of glia, and this can be explained by the rise in extracellular Ke, due to release by nerve.

Attempts to show that glia are metabolic depot ~~____~~ by radioautography did show labelled glycogen both in glia & nerve, but did not show that glia takes it up first.

Glia are not a tight barrier to current & diffusion; the gaps between are ample.

Today Bertil Hille of Rock. Univ. gave a very interesting talk separating K & Na conductance in frog single node preparation.

He is a graduate student

Advisers are Connelly, Mauro & Dodge

Using voltage clamp prep. of Dodge & Frankenhauser

Online computer facility of Hartline.

Tetrodotoxin and Saxitoxin } selectively (can be graded) & reversibly block only the Na conductance, without change the on or off time constants.

(probably reduce number of channels available)

See left.

Ol Bulb Xeroxes.

April 17 → May 1 prepared original and three xerox copies
Copy 1 ≡ master used for revisions
Copy 2 = read by Zimm
Copy 3 = lent to Tom Reese & Milton

On May 2, got complete 43 references typed.

~~On May 3~~ Then renumbered all references in the Master Xerox & made other corrections.

May 3 Renumbered references & made corrections on the original

Now have 1 Title page
61 pages of text
5 " of references 62–66
6 " figure legends 67–72
15 figures
88 pages altogether

May 4 Request twelve copies to be xeroxed downstairs

Plan to send 3 to Gordon (one for Charles Phillips)
2 for Master & Spare
2 for Zim & clearance
3 for Reese, Nelson, Frank
10

April 1967

Concentrated on completing draft of O-Bulb paper.
Gordon was here 1st week of April
I kept ball rolling & got typing & xeroxing
done during remainder of April

← References renumbered May 2 & 3

Also, planning trip to Ravello: red tape
reservations etc.

Also, gave Seminar at Yale on April 26.
Prof. Talbot Waterman billed my seminar as
the
Quastler Memorial Lecture in Theoretical Biology

~~On~~ April 26; also met colleagues: Goldsmith who sent greetings to Hagins
Waterman & collaborators have e.m. & physical
evidence on dichroism (sens. to polarized light)
in crab eyes.

On April 27 visited Guy Hunt, ~~Knox~~ Chandler, Joe Hoffman
& also Nichols' colleague, Dennis Baylor
who told me about Leech results.

May 1967
Planning trip to Ravello & making arrangements

received letter & enclosures from Walter Freeman, May 11

Got back 12 xerox copies of O-Bulb manuscript May 18

Got letter from J. Neurophysiol accepting Synaptic Potential paper May 18

Got PanAm tickets May 15–18

Xerox Copies
1 to John Evans
1 for clearance
2 for Gordon
1 at home
1 for Milton & Tom
1 for Phil & K.
7

one more for Gordon 8/7/67

July 17, 1967 returned from trip {Ravello / Pisa}
found pile of journals, mail & advt.

Henneman wanted theoret EPSP manuscript
Lechner invitation for seminar
Ted Evans for reprints
Must write Hellerstein
Must get in touch with Gordon Shepherd &
collect comments of Tom, Milton, Phil & Kay on O'Bulb.
Must prepare trip report

July 24, 1967 Past week, went thru mail & journals
Responded to MacKay's invitation to Keele
Sent copy to Henneman
* Worked on manuscript & finally wrote Arbib + Hellerstein
Went over Bob Burke's manuscript for him
& found some misunderstanding of the
consequences of uniform synaptic input.
* Galley Proofs from J. Neurophysiol.
August 67 worked on O'Bulb revisions
collecting comments, etc.
Aug. 18 saw Roger Nicoll who left me a manuscript.
saw Theodore Tarby grad student UCLA Adey
was Cal. Tech. undergrad with van Harreveld
Doing Ph.D. on impedance studies.
Was interested to know if I have more theory.
I referred him to Ranck & urged him to
watch for volume changes.

apparently Ca^{++} added reduces cortical impedance. ← I urged him to watch for volume change

Aug 21 – 25 was a very hectic week
several conferences over Udo's eye, including
several consultations & literature search.

Also Am. Physiol. Soc. meetings at Howard.
saw Walter Freeman et al
received invitation from Rosen for his textbook
Also read Roger Nicoll's manuscript
& " MacGregor's " for Biophys J.

Aug 28 – Sept. 1 writing up comments for Nicoll & colleagues
" " " Biophys J.

Plan for Keele Symposium (Sept. 4–8)

Also must write note to Caianiello
phone Rosen
phone Cechner

Also took care of contacts with Artificial Kidney
& " Heart
for brothers Pallotti in Bologna; hope trouble was merited

Tom Smith & Phil Nelson made more
comments on O'Bulb manuscript.

Sept. 3-8 went to
Keele Symposium
Dept. of Communications (Prof. Mackay)
Univ. of Keele
Staffordshire, England

Eccles & others were very complimentary about the dendrodendritic story.
Philips said he was glad he had not fallen into the trap of publishing conventional interpretations of fields.
Jung was pleased to see dendritic slow potentials back.

Later when I asked Philips, he said he felt it entirely reasonable to wonder if short axon Golgi cells could work in the same way.

Also, the EPSP shape story went over without challenge & later Szentágothai told me that his recent anatomical studies show that I-A afferents do go to motoneuron soma first, but then climb out with many synapses on dendrites!

Eccles was very complimentary at the Dinner, singling me ~~out~~ as one from whose presentation he had really learned something important. Another day, he urged me to write up the theory in a monograph.

Thursday Sept. 28
Notes for talking with Zim & John Evans.
Previous day, Ed advised more important to get on with good work than to get involved in writing treatises.
↖ with help of good collaborator.

Problems to discuss & assess

1. General: neural coding
   both short term & long term memory
2. General: spatial ensemble of information (set of neurons)
   (as opposed to time series: interval histogram of spikes of one neuron)
3. Encoding & Decoding: roles of dendrites
4. Specific simulation ~~explorations~~ with small ensemble:
   ⓐ olfactory bulb
   ⓑ retina
   ⓒ other (? cerebellum)
5. Polish off older manuscripts
   ⓐ field around sphere
   ⓑ non-linear membrane model
   ⓒ effect of field on neuron
   ⓓ multiple time constants.

added a little later {
6. Single versus group of motoneurons: dipole/multipole
   might do with John & Phil
7. With Phil, simultaneous estimates of ρ, τ, Z_m, R_m
}

Sept. 10 – 29 were hectic because of family complications with Udo at Johns Hopkins with surgery for detached retina & also an overseas visitor (Hess) for part of that time.

Also, Eccles wrote (Sept. 18) suggesting Symposium in April
Bullock phoned for NRP Work Session Jan 20-22
Caianiello { sent reminder for Ravello manuscript
{ sent invitation to Russian Cybernetic Symp
Walter Freeman sent data from O'Bulb
Hellerstein sent revised manuscript.

Finally wrote Cechner at Case Sept. 27
Caianiello "
Short notes to Walter Freeman Oct. 4
Bob Livingston "
Donald Mackay "

Talked to Eccles by phone & then contacted Shepherd
Reese
Nelson
Dowling

Oct. 9 Was invited by Paul Sykondis, Purdue, to present a major talk to Six AerospaceSciences Meeting of Am. Inst. of Aeronautics & Astronautics & this confirmed by Sp. Delivery letter. I declined Oct. 11.

Oct. 12 Wrote MacKay comments on his draft report on the Keele Symposium.
Also wrote referee comments for Windle

Must respond to Caianiello, Rosen, Eccles, finish O'Bulb paper, finish dendrites with Phil Nelson.

Oct. 6 – 11 worked with many interruptions on the AC admittance of finite dendrites and how this affects relations between ρ, Z_m, frequency & phase shift, because Phil Nelson needs this for paper he is writing with Lux.

Idea for a new experiment testing theory for ρ and Z_m.

1st. est. ρ & Z_m with dendrites intact

Then repeat observations with dendrites cut.

& use theoretical results for cut dendrites.

Discuss with John Evans & Phil Nelson whether to do more experiments on single motoneuron vs motor nucleus to test theoretical ideas I discussed with them. Check back to earlier notebook.

For dendrites & soma together, i.e. whole neuron

$$Y_N = Y_S + Y_D$$

for finite (sealed end) AC Steady State

$$Y_N = (1+j\omega\tau) G_s + G_\infty \sqrt{1+j\omega\tau} \tanh\{Z_m\sqrt{1+j\omega\tau}\}$$

$$= G_S\left[1+j\omega\tau + \rho^* \sqrt{1+j\omega\tau} \tanh\{Z_m\sqrt{1+j\omega\tau}\right]$$

where $G_S = \frac{G_N}{\rho+1}$ and $\begin{cases} \rho = \frac{G_\infty \tanh Z_m}{G_S} \\ \rho^* = \frac{G_\infty}{G_S} = \frac{\rho}{\tanh Z_m} \end{cases}$

open end. See 1959 reprint p. 498

Notice that for killed end.

$$V = \frac{V_0 \sinh[(X_0 - X)/\lambda_0] - E\sinh(X/\lambda_0)}{\sinh(L_0/\lambda_0)}$$

$$\frac{\partial V}{\partial X} = \left(\frac{-1}{\lambda_0}\right) \frac{V_0 \cosh[(X_0-X)/\lambda_0] + E\cosh(X/\lambda_0)}{\sinh(L_0/\lambda_0)}$$

at $X=0$, $Z=0$

$$\left[-\frac{\partial V}{\partial Z}\right]_{Z=0} = V_0 \coth Z_m + \frac{E}{\sinh Z_m}$$

killed end draws const. current from electrode at $Z=0$ but would not contribute to AC admittance

10/16/67 Summarize A.C. Steady State Admittance in finite Cylinder.

This refers back to 2/9/63 notes on yellow legal paper.

DE $\frac{\partial^2 V}{\partial Z^2} = V + \tau \frac{\partial V}{\partial t}$

DC steady state $\frac{\partial^2 V}{\partial Z^2} = V$; $V = Ae^{-Z} + Be^{+Z}$

AC steady state $\frac{\partial^2 U}{\partial Z^2} = (1 + j\omega\tau)U$ where $V = Ue^{j\omega t}$

$U = Ae^{-Z\sqrt{1+j\omega\tau}} + Be^{+Z\sqrt{1+j\omega\tau}}$

B.C. for finite length, sealed end

$\frac{\partial V}{\partial Z} = 0$ at $Z = Z_m$

$\left\{ \begin{array}{l} V = V_0 e^{j\omega t} \\ U = V_0 \end{array} \right\}$ at $Z = 0$

(For open end see left)

In each case, $Y_0 = \frac{I_0}{V_0} = \frac{1}{V_0}\left(\frac{1}{r_i}\right)\left(-\frac{\partial V}{\partial x}\right)_0 = \frac{1}{V_0}\left(\frac{1}{\lambda r_i}\right)\left(-\frac{\partial V}{\partial Z}\right)_0$

$= \frac{G_\infty}{V_0}\left(-\frac{\partial V}{\partial Z}\right)_0$, where $G_\infty = \frac{1}{\lambda r_i} = \frac{r_m}{\lambda} = \sqrt{g_m g_i}$

Summarize result for dendrites only

DC semi-infinite $Y_0 = G_\infty$

DC finite sealed end $Y_0 = G_\infty \tanh Z_m$

" " open end $Y_0 = G_\infty \coth Z_m$

AC semi-infinite $Y_0 = G_\infty \sqrt{1 + j\omega\tau}$

" finite sealed end $Y_0 = G_\infty \sqrt{1+j\omega\tau} \tanh\left\{Z_m\sqrt{1+j\omega\tau}\right\}$

" " open end $Y_0 = G_\infty \sqrt{1+j\omega\tau} \coth\left\{Z_m\sqrt{1+j\omega\tau}\right\}$

Where complex quantities must be expanded.

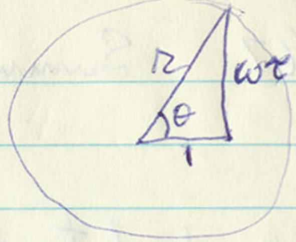
From 1960 paper, let $1 + j\omega\tau = r e^{i\theta}$

where $r = \sqrt{1+\omega^2\tau^2}$

$\tan\theta = \omega\tau$

$\sin\theta = \omega\tau / r$

$\cos\theta = 1/r$



$$\sqrt{1+j\omega\tau} = \sqrt{r}\, e^{i\theta/2}$$
$$= \sqrt{r}\left\{\cos\tfrac{\theta}{2} + j\sin\theta/2\right\}$$
$$= \sqrt{r}\left\{\sqrt{\tfrac{1}{2}(1+\cos\theta)} + j\sqrt{\tfrac{1}{2}(1-\cos\theta)}\right\}$$
$$= \sqrt{r}\left\{\sqrt{\tfrac{r+1}{2r}} + j\sqrt{\tfrac{r-1}{2r}}\right\}$$
$$= \sqrt{(r+1)/2} + j\sqrt{(r-1)/2}$$
$$= a + jb$$

$r = 2b^2+1$

$= 2a^2-1$

$$1 + j\omega\tau = a^2 - b^2 + j\,2ab$$

$$a^2 - b^2 = \frac{r+1}{2} - \frac{r-1}{2} = 1 \qquad a^2+b^2 = r$$
$$2ab = \sqrt{r^2-1} = \omega\tau$$

also $a = \sqrt{b^2+1}$

$b = \sqrt{a^2-1}$

for open end.

$$R = \frac{a\sinh 2aZ_m + b\sin 2bZ_m}{\cosh 2aZ_m - \cos 2bZ_m}$$

$$J = \frac{b\sinh 2aZ_m - a\sin 2bZ_m}{\cosh 2aZ_m - \cos 2bZ_m}$$

for $Z_m \to \infty$, get same as at right

for $Z_m = \epsilon$
$$R = \frac{(2a^2+2b^2)\epsilon}{1 + \frac{(2a\epsilon)^2}{2!} - 1 + \frac{(2b\epsilon)^2}{2!}} = \frac{2r\epsilon}{2r\epsilon^2} = \frac{1}{\epsilon}$$
$$J = \frac{b(2a\epsilon)^3/6 + a(2b\epsilon)^3/6}{2r\epsilon^2} = \frac{(4ab\epsilon)(2a^2+2b^2)\epsilon^2}{6 \times 2r\epsilon^2} = \frac{\omega\tau\,\epsilon}{3}$$

For finite dendrite with sealed end

$$Y_0/G_\infty = \sqrt{1+j\omega\tau}\,\tanh\{Z_m\sqrt{1+j\omega\tau}\}$$

$$= (a+jb)\tanh\{Z_m a + jZ_m b\}$$

using Dwight Tables p. 145

$$= (a+jb)\frac{\sinh 2Z_m a + j\sin 2Z_m b}{\cosh 2Z_m a + \cos 2Z_m b}$$

whereas for open end, get $(a+jb)\coth\{Z_m a + jZ_m b\}$

$$= (a+jb)\frac{\sinh 2Z_m a - j\sin 2Z_m b}{\cosh 2Z_m a - \cos 2Z_m b}$$

$$R\{Y_0/G_\infty\}_{\text{sealed}} = \frac{a\sinh 2Z_m a - b\sin 2Z_m b}{\cosh 2Z_m a + \cos 2Z_m b}$$

$$J\{Y_0/G_\infty\}_{\text{sealed}} = \frac{b\sinh 2Z_m a + a\sin 2Z_m b}{\cosh 2Z_m a + \cos 2Z_m b}$$

Notice that for very large Z_m or for very large frequency, the hyperbolic functions dominate over the circular trig fcns.

also sinh → cosh and

$$R \to a = \sqrt{(r+1)/2}$$

$$J \to b = \sqrt{(r-1)/2}$$

in agreement with older result for semi-infinite length.

For very small arguments, $Z_m = \epsilon$

$$R = \frac{2a^2\epsilon - 2b^2\epsilon}{2} = \epsilon(a^2-b^2) = \epsilon$$

$$J = \frac{4ab\epsilon}{2} = \epsilon(2ab) = \epsilon\,\omega\tau$$

$$\alpha = 2aZ_m = 2Z_m\sqrt{b^2+1} = 2Z_m\sqrt{\frac{\beta^2}{4Z_m^2}+1} = \sqrt{\beta^2+4Z_m^2}\ ; \quad b = \frac{\beta}{2Z_m}$$

$$\beta = 2Z_m b = 2Z_m\sqrt{a^2-1} = 2Z_m\sqrt{\frac{\alpha^2}{4Z_m^2}-1} = \sqrt{\alpha^2-4Z_m^2}\ ; \quad a = \frac{\alpha}{2Z_m}$$

If $\beta = \frac{\pi}{4} = .785$ and $Z_m = 1$, ($b = .392$) $\alpha = \sqrt{.616+4} = 2.15 = (\pi - .99)$ } $Z_m = \frac{1}{4}$, $\alpha = \sqrt{.616+.25} = .93$

$\frac{\pi}{2} = 1.57$ " $\sqrt{2.46+4} = 2.54 = (\pi - .60)$ } $Z_m = \frac{1}{2}$ ($b = 1.57$, $b = \beta$), $\alpha = \sqrt{2.46+1} = 1.86$

$\pi = 3.14$ " $\sqrt{9.87+4} = 3.72 = (\pi + .58)$ } $Z_m = 1$, $\alpha = \sqrt{9.87+4} = 3.72$

For open end

$$R^2 + J^2 = (a^2+b^2)\left(\frac{\cosh\alpha + \cos\beta}{\cosh\alpha - \cos\beta}\right)$$

open end

for β in 2nd or 3rd Quadrant, quotient is less than unity
for $\beta < \frac{\pi}{2}$, quotient is greater than unity
for $\beta = \frac{\pi}{2}$, quotient $= 1$

Here, for $\beta = \frac{\pi}{2}$, $R = \frac{a\sinh\alpha + b}{\cosh\alpha}$, $J = \frac{b\sinh\alpha - a}{\cosh\alpha}$

$= a\tanh\alpha + \frac{b}{\alpha}$ $\qquad = b\tanh\alpha - \frac{a}{\cosh\alpha} < b$

implies $> a$

for $\beta = \pi$, $R = \frac{a\sinh\alpha}{\cosh\alpha + 1}$, $J = \frac{b\sinh\alpha}{\cosh\alpha+1}$

$= a\sqrt{\frac{\cosh\alpha - 1}{\cosh\alpha+1}} < a$, $\qquad = b\sqrt{\frac{\cosh\alpha-1}{\cosh\alpha+1}} < b$

$$R^2 + J^2 = (a^2+b^2)\left(\frac{\cosh\alpha - 1}{\cosh\alpha+1}\right) < (a^2+b^2)$$

when $\beta = \frac{\pi}{4}$, $R = \frac{a\sinh\alpha + .707b}{\cosh\alpha - .707}$, $J = \frac{b\sinh\alpha - .707a}{\cosh\alpha - .707}$

Finite coso (sealed) was examined first & showed that for certain values of the argument $2bZ_m$ can get admittance larger than for infinite length. ∴ examine this question.

sealed end $R^2 + J^2 = \frac{(a^2+b^2)(\sinh^2\alpha + \sin^2\beta)}{(\cosh\alpha + \cos\beta)^2}$ where $\alpha = 2aZ_m$, $\beta = 2bZ_m$

$$= (a^2+b^2)\left(\frac{\cosh^2\alpha - 1 + 1 - \cos^2\beta}{(\cosh\alpha + \cos\beta)^2}\right)$$

$$= (a^2+b^2)\left(\frac{\cosh\alpha - \cos\beta}{\cosh\alpha + \cos\beta}\right)$$ which $\to 0$ as $Z_m \to 0$

For $Z_m = \infty$, get simply a^2+b^2

for β in 2nd or 3rd quadrant, quotient is ~~less~~ greater than unity

for $\beta < \pi/2$, quotient is less than unity.

for $\beta = \pi/2$, quotient $= 1$

for $\beta = 2bZ_m = \pi$, $\cos\beta = -1$ and get $(a^2+b^2)\left(\frac{\cosh\alpha + 1}{\cosh\alpha - 1}\right)$ which is greater than (a^2+b^2)

$\alpha = \frac{a}{b}\pi$

To understand intuitively

when $\beta = \frac{\pi}{2}$, $R = \frac{a\sinh\alpha - b}{\cosh\alpha}$ ($= a\tanh\alpha - \frac{b}{\cosh\alpha}$) $< a$, $J = \frac{b\sinh\alpha + a}{\cosh\alpha}$ ($= b\tanh\alpha + \frac{a}{\cosh\alpha}$) $> b$ (implied)

when $\beta = \pi$, $R = \frac{a\sinh\alpha}{\cosh\alpha - 1}$, $J = \frac{b\sinh\alpha}{\cosh\alpha - 1}$

$$= a\sqrt{\frac{\cosh + 1}{\cosh - 1}} > a, \quad = b\sqrt{\frac{\cosh + 1}{\cosh - 1}} > b$$

when $\beta = \frac{\pi}{4}$, $R = \frac{a\sinh\alpha - .707b}{\cosh\alpha + .707} < a$; $J = \frac{b\sinh\alpha + .707a}{\cosh\alpha + .707}$

$= .785$

$b = \frac{.785}{2Z_m}$

$\alpha = \sqrt{.616 + 4Z_m^2}$

$a = \frac{\alpha}{2Z_m} = \sqrt{b^2+1}$

11/15/67

Received letter from Eccles asking me to firm up Symposium

I have telephoned Shepherd
Dowling
Reese
Nelson
Bennett

to firm up ~~titles~~

They are to return calls 11/16/67

New simple title suggested by Eccles is

New Developments in Vertebrate Synaptology

11/15/67

There are more loose notes related to the previous pages. Reprint requests pouring in for EPSP papers

Last two weeks were devoted to many small projects

1. Manuscript for Caianiello (Nov. 2)
2. Referee Job for Brookhart
3. Letter to Eccles
4. Several conversations with John Evans exploring research ideas

Need fresh notes on this; also see p. 173

5. Ed asked me to address NIAMD Counselors on Nov. 17, allowing 50 minutes (40+10)

Must Review notes This afternoon

Must Polish off Olfactory Bulb manuscript

Plan to soon
Order NY Acad. Reprints
write J.Z. Young who wrote about amacrine cells
phone Rosen (re chapter)
write Abernethy (Buffalo) } turn down
Jöbsis (Duke) } seminar offers

arrange to go over olfactory glomerular fine structure with Reese & Evans

write St. Agothai ? synapses on dendrites
? write Hellerstein, Freeman

Phil Nelson ? re his manuscript.

5/11/67

Received letters ^Wed^ May 10

K. S. Cole

Also mixed feelings

~~Thinks~~ Thinks that Macey is sounder

Thinks that Manual probably has lowdown

Goldmann ~~going~~ to Philadelphia (New Med. School)

Story about Claire Booth Luce (recent convert)

Osterhout said one should always be looking for a ^better^ job

Bronk used every such opportunity to visit a place & get to know who was doing what.

(7) tried to get Freygang to cover ^for^ him during Sabbatical but could offer very little

I said letter grandiose; K.C. said he feels that way too.

One can always say that one likes present situation very well, but that one is willing to be shown that other is better.

Thurs - Sept 28

Must talk with Zim
& with John Evans

Ed suggests more important to exploit lead than to write treatises. Get best collaborator.

Problems:

1. General: neural coding
   both short & long term
2. General: spatial ensemble of information
   (spatio-temporal)

3. Encoding & Decoding

4. Specific simulation explorations with small ensemble.
   (a) olfactory bulb
   (b) retina
   (c) ~~other~~ cerebellum ×
   (d) other

5. Polish off older manuscripts
   (a) field around sphere
   (b) non-linear system
   (c) effect of field on neuron
   (d) multiple time constants

Equalizing Time Constants and Electrotonic Length of Nerve Cylinders and of Neurons

Equalizing Time Constants and Nerve Length

6/7/66

For anom red.

Suppose we discard G_r
& use only G_ϵ & G_j

At rest, suppose $G_\epsilon = 0.1\, G_j$

Control, with G_ϵ + G_j ~~constant~~, looks at
response to current step. ~~+ [illegible]~~ —

Next, have G_ϵ follow variable ~~$\propto V^2$~~
which grows as V^2

10/5/66

Hyperpol series

Book 9				for control foot to peak	halfwidth	Comment
p. 69	615.831	ε = .1 in ①, .3 in ④	τ/25	.14	.99	too early
73	.832	.1 in ①, .3 in ③ & ④	τ/25	.33	1.17	fair
74 & 80	.833	.1 in ①, .4 in ④, .5 in ⑤	τ/25	~.64		
82	.834	.1 in ①, .3 in ③, .4 in ④	"	.37	1.23	fair

For 17% hyperpol in ①, this last gave 17% slope increase, 10.9% peak increase

Refer to pp. 84 & nearby. p. 83 weighted mean factor -

p 87 hyperpol electrotonus, p. 88 for assessment

				peak time		
p. 92	615.835	ε = .1 in all five	τ/25	.20	slope 16%	peak 14.6%
91	615.836	.1, .2, .3, .4, .5	"	.40	14%	10.7%

Change to 20% hyperpol & τ/50

p. 96	615.837	ε .1 in all five	τ/50	.12	18.5%	17.2%
95	.838	.1, .2, .3, .4, .5	τ/50	.36	17%	12%
94	.839	ε = .1 in ①, 1.0 in ⑤	τ/50	.08	→	

10/5/66 Change to 40% hyperpol & τ/25

Try	.840	ε = .1 in ①, & .6 in ④	τ/25
	.841	.1 in all five	τ/25
	.842	.1, .2, .3, .4, .5	τ/25
	.980	in ⑩ with $\lambda_{1/2}$ = 6.25 Transient go to 3.2	τ/50
	.981	①	
	.982	⑦	

He would like to receive announcements of our seminars

p. 90
Book 9

Dr. MARTIN A. GARSTENS

OFFICE OF NAVAL RESEARCH
CODE 421 PHYSICS BRANCH
WASH. D.C. 20360

OX-6-1890

He is a physicist who is interested in supporting bio physics & biomathematics

Knows George Weiss

10/6/66 → talked to Zelen, who sent him to see us, & learn about our group.

He has attended some of F. O. Schmitt's conferences & has talked with Livingston

Sept. 23

~~first called~~

Dr. James Garvey

Code
213
SY-5-5971

1st full week Dec
6+7
Dec. 5 6 7 8

Cole

1/25/67

→ Miledi commented that their method of replacing Ca with Mg, could be used to ~~test~~ if an ~~chemical transmitter~~ ~~action potential~~ is required to mediate the dendro-dendritic pathway.

They use this at the n.m jcn to prevent ACh release by an action potential.

gemmule as key to learning

provides (A) presynaptic specificity

(B) post synaptic link to success of firing (? reward)

gemmules have lots of vesicles

3/29/68

Delivered O'Bulb manuscript.

Wrote notes to

Windle

Rudomin

Goldstein (student at Chicago)
(Dorothy hasn't typed yet) }

Livingston

Bullock

Dec ~~1967~~ 67 & early January 68

slowed down by flu
did some referee work
also wrote J. Z. Young
Scheibels
Jöbsis & Moore

Work on field of neuron
also wrote Umigo & checked out tape recorders

Stan Appel 3/10/64 p. 90 Book 3

Also see p. 91 for Fitzhugh's reaction to my active membrane model

See p. 92 Van Buren records & questions he faced

Take Potential paper charts
to the art department.

Also, photograph 5 ⊕ plot

dig out footnotes
sketches of diagram figures
& next text.

Nelson & Van Buren

1/5/65 ref p. 2 of Book 6

See also p. 77 of Book 5

pp 25 - 31 2/3/65

pp 40 - 41
44 - 49

p. 83

xerox copy sent

Memo to Bob Burke and Phil Nelson 1/31/67
from Wil Rall
Re: R_N, ρ, and surface area of rescaled neuron models.

For simplicity, consider N dendritic trees, each represented by an equivalent cylinder of length, L, and diameter, d. The total dendritic surface area (neglecting ends of equiv. cylinder) can be expressed

$$A_D = NL\pi d .$$

For simplicity, consider a spherical soma of radius, a. The soma surface area can be expressed

$$A_S = 4\pi a^2 .$$

The dendritic to soma surface area ratio is thus

$$A_D/A_S = \frac{NLd}{4a^2} .$$

This remains constant with rescaling, provided that $NLd \propto 4a^2$. The simplest case would be, N constant, and $L \propto d \propto a$. However, more complicated cases are also possible.

The combined dendritic input conductance can be expressed

$$G_D = N\, G_\infty \tanh(L/\lambda)$$

where, for each equivalent cylinder

$$\lambda = \tfrac{1}{2}\sqrt{R_m d/R_i} \propto \sqrt{d} \quad \text{for } R_m \text{ and } R_i \text{ const.}$$

and $$G_\infty = \frac{1}{\lambda r_i} = \frac{\lambda}{r_m} = \frac{\lambda \pi d}{R_m}$$

$$= \frac{(\pi/2)}{\sqrt{R_m R_i}}\, d^{3/2} \propto d^{3/2} \quad \text{for } R_m \text{ and } R_i \text{ const.}$$

$$= \frac{C\, d^{3/2}}{\sqrt{R_m}} \quad \text{where } C = \frac{\pi/2}{\sqrt{R_i}}$$

Special cases: A. for $L/\lambda > 2.3$, $\tanh(L/\lambda)$ differs from unity by less than 2%

Then $$G_D \approx \frac{N\lambda}{r_m} = \frac{N C d^{3/2}}{\sqrt{R_m}}$$

B. for $L/\lambda < 0.25$, $\tanh(L/\lambda)$ differs from L/λ by less than 2%

Then $$G_D \simeq \frac{NL}{r_m} = \frac{NL\pi d}{R_m} = \frac{A_d}{R_m}$$

In other words, for very short equivalent cylinders,

$$G_D = \frac{A_D}{R_m}$$

But, for very long cylinders

$$G_D = \left(\frac{\lambda}{L}\right)\left(\frac{A_D}{R_m}\right)$$

and, in general, for all lengths,

$$G_D = \left(\frac{A_D}{R_m}\right)\left(\frac{\lambda}{L}\right)\tanh(L/\lambda).$$

This is a new expression that was not in my 1959 paper.

The soma conductance is

$$G_S = \frac{A_S}{R_m}$$

The whole neuron conductance

$$G_N = \frac{1}{R_N} = G_S + G_D = \frac{A_S + A_D\left(\frac{\lambda}{L}\right)\tanh(L/\lambda)}{R_m}$$

$$R_N = \frac{R_m}{A_S + A_D\left(\frac{\lambda}{L}\right)\tanh(L/\lambda)} = \frac{R_m}{(\rho+1)A_S}$$

R_m uniform

$$\rho = (A_D/A_S)(\lambda/L)\tanh(L/\lambda)$$

These new expressions provide the relations between ρ, R_N and R_m, and areas that we need.

Now we can consider several kinds of rescaling.

I keep ρ constant, and R_m constant
if also (A_D/A_S) is constant
then L/λ must be constant $\propto L/\sqrt{d}$
and also $NLd = 4a^2$

∴ If the number of dendritic trees remains constant, it is necessary that

$$L^3 \propto d^{3/2} \propto a^2$$

or that $L \propto a^{2/3} \propto A_s^{1/3}$
and $d \propto a^{4/3} \propto A_s^{2/3}$

For such scaling, $R_N \propto \dfrac{R_m}{A_s}$

However, other kinds of scaling could also be considered.

II Let ρ vary

Suppose, for example, that $L \propto d \propto a$, preserving A_D/A_S, but not ρ.
Then
$$L/\lambda \propto L/\sqrt{d} \propto \frac{a}{\sqrt{a}} \propto \sqrt{a}$$

This means that doubling the linear dimensions of the cell would increase L/λ by $\sqrt{2} = 1.414$
And the surface area would increase fourfold.

From an initial value of $L/\lambda = 1.0$

$$\frac{\rho_2}{\rho_1} = \frac{(1.414)^{-1}}{1} \frac{\tanh(1.414)}{\tanh(1)}$$

$$\doteq (0.707)\left(\frac{.889}{.762}\right)$$

$$\doteq \frac{.628}{.762} = 0.824$$

~~$\frac{R_{N_2}}{R_{N_1}} = \frac{1 + \ldots \rho_0}{4(1 + 0.824\rho_1)}$~~

Notice that because $R_N = \frac{R_m}{A_s(\rho+1)}$

If R_m is kept constant
and linear dimensions are doubled

$$\frac{R_{N_2}}{R_{N_1}} = \frac{1}{4}\frac{(1+\rho_1)}{(1+0.824\rho_1)}$$

If $\rho_1 = 5$, then get $\frac{6}{4(1+4.12)} \simeq \frac{6}{20.5}$

$$= \frac{1}{3.4}$$

i.e. Whole neuron resistance is decreased by a smaller factor (3.4) than would have been the case (4.0) for ~~[illegible]~~ Case I.

To put this another way: for case II, with $L \propto d \propto a$, reducing R_N by a factor of 4 means increasing the surface area by more than a factor of 4.

There are many other cases.

(A) Suppose the number of dendritic trees, N, varied with neuron size.

(B) Suppose R_m varied with neuron size.

(c) Suppose A_D/A_S were not preserved.

(d) Suppose the relation of L to a and d to a were different from cases I or II.